NBSIR 75-947

COLLECTED EXECUTIVE SUMMARIES STUDIES OF THE NATIONAL MEASUREMENT SYSTEM 1972-75

Raymond C. Sangster

Office of the Deputy Director
Institute for Basic Standards
National Bureau of Standards
Boulder, Colorado 80302

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U.S. DEPARTMENT OF COMMERCE, Elliot L. Richardson, Secretary
Edward O. Vetter, Under Secretary
Dr. Betsy Ancker-Johnson, Assistant Secretary for Science and Technology

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Acting Director

FOREWORD

The concept of a National Measurement System has, for many years, provided a useful focus for the considerations important to physical measurements in our technology intensive economy. Dr. R. D. Huntoon, in his October 6, 1967, article in Science, emphasized the basis for a systems viewpoint in interrelated measurements activities and the idea has continued to evolve. Today, we think of the U.S. National Measurement System in terms of all the intellectual, functional and institutional activities which involve measurements throughout our society. Moreover, we seek to understand more completely the structural nature of this system and its architectural needs.

There have been a number of approaches to the study of our national system for physical measurements. The present series of studies was initiated in 1972 by Dr. Ernest Ambler, then Director of the Institute for Basic Standards. It was Dr. Ambler's purpose to organize the essential information necessary for the effective management of NBS resources and to promote the direct interaction between IBS staff members and the communities of users they serve.

This document reflects the results of the intensive studies carried out during the period from 1972 - 1975. It is important to recognize that the National Measurement System is extremely complex having widely distributed elements and impacts. The detailed analysis of this system is well beyond the state-of-the-art of econometric modeling, and therefore, any study, no matter how intensive, is necessarily incomplete. Nevertheless, the information which is now in hand provides an important addition to our capability for planning and implementing the programs of IBS. It also represents a growing foundation upon which we can continue our efforts to build a more effective structure.

A. O. McCoubrey
Director, Institute for Basic Standards
National Bureau of Standards
August 1976

PREFACE

The 1972-75 Study of the National Measurement System by the NBS Institute for Basic Standards has been a massive effort involving many people in all divisions of the Institute. The information compiled in this document is one of the results of this effort, and could never have been developed without the contributions of a large number of knowledgeable individuals.

The Study was organized around a central coordinator and a group of "National Measurement System Study representatives" from the technical divisions of the Institute. The initial central coordinator was Dr. James R. Seed, a Presidential Interchange Executive from the Dow Chemical Company, on temporary assignment to the National Bureau of Standards. Dr. Seed was responsible for the initial formulation of the tactical plans for this Study, and carried the project through to the generation of a complete set of comprehensive reports on the structure and operation of the various portions of the System, in December 1973. In August 1974, I took over the central coordinator position, and worked with the Study representatives from the divisions of the Institute, to round out the pattern of the Study and to develop the final reports which are being issued by NBS for the different areas of measurement interest.

The "Executive Summaries" presented in this document were taken from the semi-final drafts of these reports. Because this document is being published before all of the individual reports have received final editorial clearance, there may be slight discrepancies between the summaries contained herein and those ultimately published with the individual reports; none of these discrepancies is expected to involve any matter of substance.

We trust that the availability of this document will be useful to many readers who need only an overview of the results of our Study of the National Measurement System. For those who want more detailed information about any part of this study, we have provided a "Report Request Card" at the back of this document, which can be used to request the specific reports wanted.

At this point, it would be customary to acknowledge by name the efforts of the secretaries and other supporting personnel without whose unstinting efforts no document of this type could be created. However, inasmuch as these summaries were generated as parts of a large number of reports, it seems most appropriate not to attempt to acknowledge these contributors by name, but simply to salute the devoted efforts of the secretaries and supporting staff members of the National Bureau of Standards, without which the work of the Bureau would be impossible.

Raymond C. Sangster
August 1976

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STUDY OF THE NATIONAL MEASUREMENT SYSTEM

Raymond C. Sangster
NBS Institute for Basic Standards
March 1976

EXECUTIVE SUMMARY

The National Measurement System consists of all of the activities and mechanisms--intellectual and operational, technical and institutional--that provide physical measurement data to allow the creation of the objective, quantitative knowledge required by our society. These data are used to describe, predict, communicate, decide, control, and react, in many aspects of our personal lives, society, science, and technology.

The system model has five levels:

I. The conceptual system, the intellectual foundation that defines the measurement quantities and units.

II. The basic technical infrastructure that provides the tools and techniques and agreements that allow the conceptual system to be reduced to practice. Component parts include the documentary specifications system, measurement instrumentation (including software), and reference materials and data.

III. Realized measurement capabilities, i.e., abilities to measure specific quantities to known accuracies under defined conditions.

IV. The institutional dissemination and enforcement network; components include NBS, state and local weights and measures agencies, standards laboratories, and some regulatory agencies.

V. End-use measurements, which all other levels of the system exist to support.

Supporting all of these levels is a central pillar of measurement science, know-how, and trained people.

Interactions among different institutional sectors of the system have been described by a direct measurements transactions matrix. Table 1 is the summary matrix developed by this study. Table 2 describes NBS outputs.

A macroeconomic study of the measurement system was based upon analyses of what people actually do on the job. The U.S. economic input-output tables provided insight into measurement instrumentation costs.

The making of physical measurements is ubiquitous. All 78 major industrial sectors, all levels of government, and consumers bought measurement equipment or labor.

Measurements cost an estimated 6% of GNP. About 85% is for labor.

Federal, state and local governments are the largest user sector, about 30% of total.

Other service industries, principally trade, utilities, transportation and communication, account for about 25%.

"High technology" manufacturing industries spend a larger share of their value-added but relatively few dollars.

Economics consultants from the University of Colorado and George Washington University contributed to the study. Measurement is part of the knowledge or information economic sector, where economic analysis is in its infancy. Preliminary correlations of measurement intensity with economic growth and productivity data for major industrial sectors reveals a significant positive correlation. Firm cost-benefit analyses are generally lacking and are difficult to effect.

Microstudies of the system were conducted in the following technical areas:

Time & frequency	Electromagnetics
Length & related dimensional measurements	Medical ultrasonics
Vibration and shock	Acoustics
Surface finish	Radiometry & photometry
Mass, volume & density	Spectrophotometry
Force	Far ultraviolet radiometry
Fluid flow	Optics
Pressure	Lasers
Temperature	Physical properties of atoms & molecules
Humidity & moisture	Surface properties
Thermodynamic properties of fluids	Ionizing radiation
Cryogenics	
Electricity	

In general, the U.S. national measurement system is doing its job adequately, at reasonable costs. For instance, in the basic areas of measurement of time, length, and mass, the system is well under control; the changes that are occurring are often very dramatic, but their focus is on economics: making new tasks economically feasible and allowing old ones to be done less expensively. Examples include dissemination of time signals by satellite, electronic distance-measuring equipment for surveying, and automated digital grocery store scales.

The most significant systematic problem is the lack of adequate mechanisms for quality assurance in the system. There is a widespread need for more "how-to" information at the working level. Inversely, NBS and other infrastructural institutions are not always aware of the real needs of the system.

Specific areas of deficiency include several in which essentially no national measurement system exists: Surface properties (of importance in such diverse areas as catalytic petroleum refining and microelectronics), because the field has blossomed so dramatically so recently. Medical ultrasonics (used for detecting cancer and monitoring the unborn), which has also blossomed very dramatically. Far ultraviolet radiometry (of importance in phototherapy of newborn infants and for monitoring the earth's shielding ozone layer), because standards capabilities have evolved only recently. Spectrophotometry (of importance in all fields of color and appearance and lighting), because inadequate national leadership has existed until very recently.

Further, there are several areas in which the measurement system will be subjected to severe strains in the foreseeable future, unless appropriately responsive steps are taken during the next several years. The most dramatic of these is the measurement system needed for the safeguards program for special (fissionable) nuclear materials. Less dramatic problems exist in other areas of governmental regulation, such as environmental protection and occupational safety and health, and control of noise pollution.

Other areas in which improvements in the system are needed include the following:

1. A firm base for measurement under dynamic, time-varying conditions, of force, fluid flow, pressure, temperature, humidity, electrical quantities, and others.

2. Similar needs for measurements made under hostile environmental conditions, such as the measurement of temperature, pressure, neutron flux, and fission rates *inside* nuclear reactors.

3. Precision characterization of many kinds of measurement transducers, especially for temperature and pressure.

4. Non-contacting, on-line, manufacturing instrumentation for measurement of surface finish parameters.

5. Flow measurements in the field, such as low air velocities for mine ventilation, water supply and waste water flows, metering of natural gas, and multi-component flow.

6. Measurement assurance for auto tire pressures and aircraft altimeters.

7. Electronic medical thermometry.

8. Measurement of moisture in grain.

9. Gathering and predicting measurement data on the thermodynamics of fluids, especially complex mixtures.

10. A measurement system and data for liquified natural gas, hydrogen as a fuel, and superconductivity in the electrical power industry.

11. Standards support to high speed, dynamic, automatic measurement systems, in electronics and electromagnetics.

12. Widely available techniques for measurement of electromagnetic interference and susceptibility phenomena.

13. Widely available 1% end-use measurements in radiometry and photometry, where 20% is common today.

14. Improvement of measurement of ionizing radiations used in medicine, to which workers are exposed, or present in the environment.

The major trends of the System are these:

Increased complexity, resulting from the ever-increasing scope of science and technology, from the development of the information economy, and from the challenge of mastering the ever-growing complexity of our society.

Increased integration, to meet the need to provide most economically and effectively the measurement data required by our society.

Improved quality control, and

Improved information resources.

Automation, to apply the computer to relax the limitations imposed by the inadequacies of human beings.

Metrication, to bring the U.S. into line with the rest of the world.

Consolidation of the scientific revolution in the basis of the system that has occurred since World War II.

As the central measurements standards institution in this country, NBS contributes to every aspect of the National Measurement System. Its two primary unique functions are custody of the national standards of physical measurement and promotion of the health of the entire National Measurement System. Specific services rendered to the System include measurement services (calibration services, Measurement Assurance Programs, time and frequency broadcasts, consultation and advice, and others), technical data, standard reference materials, coordination services, technical information services, and direct technical assistance to other agencies, public or private, while being responsive to current national concerns.

NBS is currently responding to most of the measurement system needs identified by this study. The major challenge facing the Bureau is that of wise deployment of constant or shrinking resources to support the needs of a constantly expanding National Measurement System.

Table 1. Direct measurements transactions matrix for IBS Study of National Measurement System.

DIRECT MEASUREMENTS TRANSACTIONS MATRIX FOR NATIONAL SYSTEM OF PHYSICAL MEASUREMENTS (March 1976) — USERS / SUPPLIERS	1 KNOWLEDGE COMMUNITY (Science, Education, Prof. Soc. & Publ.)	2 INTERNATIONAL METROLOGICAL ORGANIZATIONS	3 DOCUMENTARY STANDARDS ORGANIZATIONS	4 INSTRUMENTATION INDUSTRY (SIC Major Gp 30)	5 NBS	6 OTHER U.S. NATIONAL STANDARDS AUTHORITIES	7 STATE & LOCAL OFFICES OF WEIGHTS & MEASURES (OWM's)	8 STANDARDS & TESTING LABORATORIES AND SERVICES	9 REGULATORY AGENCIES (excl. OWM's)	10 DEPARTMENT OF DEFENSE (excl. Stds. Labs)	11 CIVILIAN FEDERAL GOVT AGENCIES (exc. Stds. Labs & Reg. Ag.)	12 STATE & LOCAL GOV'T AGENCIES (exc. OWM's & Reg. Ag.)	13 INDUSTRIAL TRADE ASSOCIATIONS	14 AGRICULTURE, FORESTRY FISHING; MINING (SIC Div. A & B)	15 CONSTRUCTION (SIC Div. C)	16 FOOD/TEXTILE/LBR/PAPER/LEATHER/ETC. (SIC 20-26, 31)	17 CHEM/PETROL/RUBBER/STONE/CLAY/GLASS... (SIC 28-30, 32)	18 PRIMARY & FAB. METAL PRODUCTS (SIC 33-34, 391)	19 MACHINERY EXCEPT ELECTRICAL (SIC Major Gp 35)	20 ELECTRIC AND ELECTRONIC EQPMT (SIC Major Gp 36)	21 TRANSPORTATION EQUIPMENT (SIC Major Gp 37)	22 TRANSPORTATION & PUBLIC UTILITIES (SIC Div. E)	23 TRADE/INS/FIN/REAL EST/PERS SVCS/PRINT (SIC F-H, bal 1, 27)	24 HEALTH SERVICES (SIC Major Gp 80)	25 GENERAL PUBLIC
1 KNOWLEDGE COMMUNITY (Science, Education, Prof. Soc. & Publ.)	4 1 / 6 / 2	3 1 / 2 / 1	3 1 / 3 / 1	2 1 / 3 / 1	4 1 / 4 / 2	1	1	2 1 / 2 / 1	3 1 / 2 / 2	3 1 / 3 / 1	3 2 / 3 / 2	2 / 1 / 1	2 2 / 1 / 2	1	1	2 2 / 1 / 1	3 1 / 2 / 1	3 1 / 2 / 1	2 1 / 2 / 1	3 2 / 3 / 1	3 1 / 3 / 1	2 1 / 2 / 2	3 1 / 1 / 1	2 1 / 1 / 1	2 2 / 1 / 1
2 INTERNATIONAL METROLOGICAL ORGANIZATIONS	2 1 / 1 / 1	3 1 / 3 / 1	3 1 / 2 / 2	2 2 / 1 / 1	3 1 / 3 / 2	1			1	1	1			1					1			1			
3 DOCUMENTARY STANDARDIZATION ORGANIZATIONS	3 2 / 1 / 2	3 1 / 2 / 2	3 2 / 3 / 1	3 1 / 3 / 1	3 1 / 2 / 2		3 1 / 1 / 1	3 1 / 2	3 2 / 2 / 2	3 1 / 2 / 1	2 1 / 2 / 1	1	3 1 / 2 / 2	1	2	2	2 1 / 2 / 1	2	2 1 / 2 / 1	2 1 / 2 / 1	2 1 / 2 / 1	3 1 / 2 / 2	1	2	1
4 INSTRUMENTATION INDUSTRY (SIC Major Gp 39)	2 1 / 2 / 1	2 1 / 1 / 1	2 1 / 2 / 2	4 1 / 5 / 2	3 1 / 3 / 2	1	1	3 1 / 3 / 2	3 1 / 2 / 2	3 1 / 5 / 2	3 1 / 4 / 1	3	2 1 / 2 / 1	3 1 / 3 / 2	4	3 1 / 3 / 2	3 1 / 3 / 1	3 1 / 4 / 1	3 1 / 5 / 1	3 1 / 5 / 2	3 1 / 5 / 1	3 1 / 5 / 2	3 1 / 5 / 1	3 2 / 4 / 2	3 1 / 4 / 2
5 NBS	3 1 / 3 / 1	3 1 / 3 / 2	3 1 / 3 / 2	3 1 / 3 / 2	3 1 / 4 / 1	3 1 / 1	4 1 / 2 / 2	3 1 / 3 / 1	3 2 / 2 / 1	3 / 3	3 1 / 3 / 2	2 1 / 1 / 1	2 1 / 2 / 2	4 1 / 2 / 1	1	2 2 / 1 / 1	2 2 / 2 / 2	4 2 / 2 / 2	2 1 / 2 / 1	3 1 / 2 / 1	4 1 / 2 / 1	4 2 / 2 / 2	4 3 / 1 / 2	4 3 / 2 / 2	2 1 / 1 / 1
6 OTHER U.S. NATIONAL STANDARDS AUTHORITIES	1	1		1	3 1 / 1	3 1 / 1 / 1		1	1	2	1	1	1	1	1							1	1		
7 STATE & LOCAL OFFICES OF WEIGHTS & MEASURES (OWM's)		1	1	3 1 / 1 / 1 R	4 1 / 2 / 1 R		4 / 2	1	1			3 1 / 1 / 1	1	1		3 1 / 2 / 2	1		3 1 / 2 / 1		1	2	4 / 3 / 1		4 1 / 1 / 1
8 STANDARDS & TESTING LABORATORIES AND SERVICES	2 1 / 1 / 1		2 1 / 2 / 1	2 1 / 3 / 1 R	3 1 / 2 / 2 R			3 1 / 3 / 1	2 1 / 2 / 2	3 1 / 3 / 1	3 1 / 2 / 1	1	3 / 2 / 1	1	1	1	2 1 / 2 / 1	3 1 / 2	3 / 1 / 1	3 1 / 2 / 1	3 1 / 3 / 1	3 2 / 2 / 2	3 1 / 1 / 1	3 2 / 2 / 2	
9 REGULATORY AGENCIES (excl. OWM's)	3 1 / 1 / 2		3 1 / 2 / 2	3 1 / 2 / 2 R	3 2 / 2 / 2 R			3 1 / 2 / 2 R	3 2 / 3 / 1	2 1 / 1 / 1 R	3 1 / 2 / 2 R	1 / R	2 1 / 2 / 2 R	4 2 / 2 / 1 R	4 1 / 1 / 2 R	4 2 / 2 / 1 R	3 1 / 2 / 1 R	3 1 / 2 / 1 R	4 1 / 2 / 1 R	3 2 / 2 / 1 R	3 1 / 2 / 2 R	3 1 / 2 / 2 R	3 1 / 2 / 2 R	4 2 / 2 / 3 R	3 1 / 2 / 2 R
10 DEPARTMENT OF DEFENSE (excl. Stds. Labs)	3 2 / 2 / 2		3 1 / 2 / 1	3 1 / 3 / 2 R	2 1 / 3 / 1 R	1		3 1 / 3 / 1 R	1	3 1 / 7 / 1	3 1 / 2 / 1		2 1 / 1 / 1				2 1 / 1 / 1 R	3 1 / 2 / 1 R	3 1 / 2 / R	3 1 / 4 / 2 R	3 1 / 4 / 2 R	2 1 / 2 / 2 R	2 / R	1 / R	
11 CIVILIAN FEDERAL GOV'T AGENCIES (excl. Stds. Labs & Reg. Ag.)	3 1 / 2 / 1		2 1 / 2 / 2	2 1 / 2 / 2	3 1 / 3 / 1	1		2 2 / 2 / 1	2 1 / 2 / 2	2 1 / 1 / 1	3 1 / 7 / 2	2 1 / 2 / 1	2 1 / 1 / 2	2	1	1	2 2 / 2 / 2	3 / 2 / 1	3 1 / 1 / 1	3 1 / 2 / 2	3 1 / 2 / 1	4 1 / 4 / 1	1	2	2 / 3
12 STATE & LOCAL GOVERNMENT AGENCIES (exc. OWM's & Reg. Ag.)	1		1	1 / R	2 1 / 1 / 1 R	1	1 / R	1 / R	1	1	1	3 2 / 6 / 2	1	1	2	1	1	1	1		1	1	1	1	1
13 INDUSTRIAL TRADE ASSOCIATIONS	2 / 1 / 1	1	2 1 / 3 / 2	2 1 / 2 / 2	2 1 / 2 / 2		1	3 1 / 1 / 1	2 1 / 2 / 2	2 1 / 1 / 1	2 1 / 1 / 2	2 2 / 1 / 2	2 1 / 2 / 1	1	1	1	2 1 / 1 / 1	1	2	2 1 / 2 / 1	2 1 / 1 / 1	2 1 / 1 / 1	1	1	1
14 AGRICULTURE, FORESTRY FISHING; MINING (SIC Div. A & B)	1		2 1 / 1	1 / R	2 2 / 1 / R		1 / R	1 / R	1	1	2	1	1	2 / 5	1	2	2	2	1	1	1	2	1		1
15 CONSTRUCTION (SIC Div. C)	1		1	1 / R	1 / R		1 / R	1 / R	1	1	1	1	1	1	6			1 / R	1	1	1	1	1		1
16 FOOD/TOB/TEXTILE/APPAREL/LBR/FURN/PAPER/LEATHER (SIC 20-26, 31)	1		3 1 / 1 / 1	3 2 / 1 / 2 R	3 2 / 1 / 2 R		2 / R	2 / 1 / R	3 1 / 1 / 2	1	1	1	3 1 / 2 / 2	1	1	2 1 / 6 / 1		1 / R	1 / R	1 / R		1 / R	1		2
17 CHEM/PETROL/RUBBER/PLASTICS/STONE/CLAY/GLASS (SIC 28-30, 32)	2 1 / 2 / 1	1	2 1 / 2 / 2	2 1 / 2 / 1	3 2 / 2 / 2		1	2 / 1 / 1	2 2 / 2 / 2	2 1 / 1 / 1	2 2 / 2 / 2	1	2 1 / 1 / 1	2	1	1	2 1 / 6 / 1	1	1	1	1	1	1	1	1
18 PRIMARY & FAB. METAL PRODUCTS (SIC 33-34, 391)	2 1 / 1		3 / 2	3 1 / 2 / 1 R	3 2 / 1 / 2 R		1	3 / 1 / R	2	3 1 / 2 / 1	2	1	2	2	1	1	1	3 1 / 6	2 1 / 1	1	3 / 2	2	1	1	1
19 MACHINERY, EXCEPT ELECTRICAL (SIC Major Gp 35)	2 1 / 1	1	3 1 / 2	3 1 / 2 / 1 R	3 / 2 / R		1	2 / 1	1	3 1 / 1 / 1	3 1 / 1	1	2	2 / 2	1	1	1	2	3 1 / 6	2 / 1	3 / 2	2	2	1	2
20 ELECTRIC AND ELECTRONIC EQPMT (SIC Major Gp 36)	3 1 / 2 / 2		3 1 / 2 / 2	3 1 / 3 / 2	3 1 / 2 / 2			3 1 / 2 / 2	3 1 / 1 / 2	3 1 / 3 / 1	3 1 / 2 / 2	1	3 1 / 2 / 1	1	1	1	1	1	2	3 1 / 6 / 3	3 2 / 2 / 3	2	1	2	2 2 / 2 / 2
21 TRANSPORTATION EQUIPMENT (SIC Major Gp 37)	2 1 / 2 / 1		2 1 / 2 / 1	3 1 / 2 / 1 R	2 1 / 2 / 2 R			2 1 / 2 / 1 R	2 1 / 2 / 2	2 1 / 2 / 2	2 1 / 2 / 1	2 1 / 1 / 1	3 / 1	1	1	1	2 1 / 1 / 1	2 1 / 1 / 1	2 1 / 1	3 2 / 1 / 2	3 1 / 6 / 1	3 / 2 / 1	1		1
22 TRANSPORTATION & PUBLIC UTILITIES (SIC Div. E)	2 1 / 2 / 1		2 1 / 2 / 2	2 1 / 2 / 1 R	2 1 / 2 / 2 R	3 1 / 1 / 2	1	2 1 / 2 / 1 R	3 2 / 2 / 2	2	2 1 / 2	1	2 / 2	2	1	1	1	1	1	1	2 1 / 2 / 1	3 1 / 6 / 1	2	1	3 1 / 4 / 1
23 TRADE/INS/FIN/REAL EST/PERS SVCS/PRINT-PUB (SIC F-H, Bal. 1, 27)	1		1	2 / R	3 1 / 1 / 1 R		2 / R	1 / R	2	1	1	1	1	1	1	2	2	2	1	1	1	2	7	1	6
24 HEALTH SERVICES (SIC Major Gp 80)	1		1	2 / R	4 2 / 2 / 3 R			1 / R	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5	2
25 GENERAL PUBLIC			1 / R	2 / R	2 1 / 1 / R		1 / R		2 1 / 1 / 2 R	1 / R	2 / R	1 / R	1 / R	1 / R	1 / R	1 / R	1 / R	1 / R	1 / R	1 / R	1 / R	2 / R	2 / R	1 / R	2 1 / 7 / 1

KEY TO MATRIX ENTRIES

USERS

C	D
A	
B	R

SUPPLIERS

C - IMPORTANCE OF TRANSACTIONS

1 = Purely convenience
2 = Strongly desirable
3 = No real alternatives
4 = Essential

D - (IN)ADEQUACY OF SERVICES

0 = No improvements needed
1 = Could be improved
2 = Marginal
3 = Serious deficiencies
4 = Out of control

B - RATE OF CHANGE

N = Declining
0 = Stable
2 = Growing
4 = Growing explosively

R = Flow of requirements info dominates

A - MAGNITUDE OF TRANSACTIONS

0 = Trivial
1 = Minor
2 = Moderate
3 = Important
4-7 = Major

Table 2. Direct measurements transactions matrix for outputs of NBS.

DIRECT MEASUREMENTS TRANSACTIONS MATRIX FOR OUTPUTS OF NBS USERS MEASUREMENT SECTOR	KNOWLEDGE COMMUNITY (Science, Education, Prof. Soc. & Publ.) 1	INTERNATIONAL METROLOGICAL ORGANIZATIONS 2	DOCUMENTARY STANDARDS ORGANIZATIONS 3	INSTRUMENTATION INDUSTRY (SIC Major Gp 38) 4	* NBS 5	OTHER U.S. NATIONAL STANDARDS AUTHORITIES 6	STATE & LOCAL OFFICES OF WEIGHTS & MEASURES (OWM's) 7	STANDARDS & TESTING LABORATORIES AND SERVICES 8	REGULATORY AGENCIES (excl. OWM's) 9	DEPARTMENT OF DEFENSE (excl. Stds. Labs) 10	CIVILIAN FEDERAL GOV'T AGENCIES (exc. Stds Labs & Reg.Ag.) 11	STATE & LOCAL GOV'T AGENCIES (exc. OWM's & Reg. Ag.) 12	INDUSTRIAL TRADE ASSOCIATIONS 13	AGRICULTURE, FORESTRY FISHING; MINING (SIC Div. A & B) 14	CONSTRUCTION (SIC Div. C) 15	FOOD/TEXTILE/LBR/PAPER/LEATHER/ETC. (SIC 20-26, 31) 16	CHEM/PETROL/RUBBER/STONE/CLAY/GLASS.. (SIC 28-30, 32) 17	PRIMARY & FAB. METAL PRODUCTS (SIC 33-34, 391) 18	MACHINERY EXCEPT ELECTRICAL (SIC Major Gp 35) 19	ELECTRIC AND ELECTRONIC EQPMT (SIC Major Gp 36) 20	TRANSPORTATION EQUIPMENT (SIC Major Gp 37) 21	TRANSPORTATION & PUBLIC UTILITIES (SIC Div. E) 22	TRADE/INS/FIN/REAL EST/PERS SVCS/PRINT (SIC F-H, bal I, 27) 23	HEALTH SERVICES (SIC Major Gp 80) 24	GENERAL PUBLIC 25
1 TIME & FREQUENCY	2 3	3 1 4 2		3 1 3	3 4	3 1 3	3 1 2 2	3 1 3	3 3	3 ? 4	3 3	1		4 4						1	1	3 1 4	3		2 3
2 LENGTH & RELATED DIMENSIONAL MEASUREMENTS	1 1 1	3 1 4	2 1 2 2	3 1 3	2 1 3		3 1 1 N	3 1 4		1	1		3	4 1 4 2	1		3 1 3	3 1 4	3 1 4	3 1 3 2	3 1 3 N	1	3 1 1 N		1 1 1
3 VIBRATION & SHOCK	3 2 2 2	2 3 1 2	2 2 2 2	2 2 2	2 2 1 2			2 1 2	1	3 1 1 N	2 1 1 2								2 3 1	2 3 1	3 2 2 1	2 2 1			2 3 1
4 SURFACE FINISH	3 1 2 2	3 2 2 2	3 1 3 2	2 1 2 2	3 1 2			3 1 2		3 1 2	2 1 1		3 1 2 2			3 2 1 2	2 2 1	2 1 2	2 1 2	3 2 2 2	2 1 1 2			2 2 2	
5 MASS, VOLUME & DENSITY	4 1 4	4 1 4 3	2 1 3	2 1 2 1	4 2 3		4 1 4 2	2 2	3 1 3	1 2 N	2 1		2 1 1	2 2 1		2 1	2 2 1	1	2 1 2 1					1 2 N	
6 FORCE	2 3 2	2 4	2 3 2	3 3	2 4		1 1	3 3	3 3 2	1 4 N	2 4 2	2 3	1 2	1 1	1 1	1 2	1 2	1 2	1 3	1 2	1 2	1 2	1 2		1 1
7 FLUID FLOW	2 1 3 2		2	3	3 1 3 2			3 3	3 3 2	3 3	3 3	2 1 2	2	2 2	2 1 2		2 2				2 1 2	2 1 3			2 1 1
8 PRESSURE	3 2 1	3 2 1 1	3 2 2	3 4 4	4 3		1	3 1 2	3 2	3 3	4 3 2 1		2 1 2 1	1	1	2 1 2 1	2 1 3 1	1	2 2	3 4 1	4 1 4 1	4 1 4	1	1	3 1 1
9 TEMPERATURE	3 3 3	4 2 3 2	2 1 3 2	2 3 3 2	2 3 3 2		2 1 1 2	2 3 3 2	2 3 2 2	2 3 3	2 3 3		2 1 2 2	2 1 2 2		2 1 2 2	2 1 3 2	2 1 3 2	2 1 3 2	2 1 3 2	2 1 3 2	2 1 2 2	2 1 1 2	3	1 1 1
10 HUMIDITY & MOISTURE	2 1 2		2 3 2	3 1 3	2 1 2		3 3 2 2	3 1 3		3 1 3	2 2 3	1		3 3 3 2		3 3 3 2	2 2 1		2 1 2	2 2 1	3 1 2			1	1 1
11 THERMODYNAMIC PROPERTIES OF FLUIDS	4 2 3 1	4 1 3 2	4 2 3 1	3 1 3 2	4 1 3 1			3 1 2 2	2 2 2 3	3 1 4 1	3 2 4 3	3 1 2 2	2 2 3 3	2 3 1 2		X	2 3 3 3	1 1 1 2	2 1 1 2		2 1 1 2	2 2 2 2			
12 CRYOGENICS	4 1 4	4 1 2 2	4 1 3 2	3 1 3 2	4 1 4 2	3 2 1 2	3 1 2 2	2 2 2	2 1 1 2	3 4 2	2 1 4 2	2 1 2 2	2 1 4 2				2 1 3 2				2 1 3 2	2 1 3 2	1		1 2 1 2
13 ELECTRICITY	3 2 3 3	3 1 3 2	2 1 3 3	4 1 4 3	4 1 4 3		1	3 2 4 2	3 1 3 3	2 2 2 2	3 1 3 2	3 1 2 2	1 1 2 2				3 1 1 2	3 2 1 2	1	3 1 3 2	3 1 3 2	3 1 4 1		2 1 2 2	
14 ELECTROMAGNETICS	3 2 4 2	3 2 3 1	2 2 2 1	3 2 4 1	3 1 4 1			3 2 4 1	3 2 2 1	1 1 3	3 2 3 1		2 2 1 1						1	3 2 3 1	3 2 3 1	4 3 3 3		1	
15 MEDICAL ULTRASONICS	3 2 2 3	2 2 4	2 2 2	2 3 2 3	2 1 1				3 1 3 2		1		2 1 2 1											3 2 1 2	
16 ACOUSTICS	2 2 3 N		2 1 3 1	2 1 3 4	2 1 3 2			2 1 2 1	3 3 4 1	2 1 2	2 3	2	3 2 3 1		2		1			2	2 1 3 2			2 3 1 2	2
17 RADIOMETRY & PHOTOMETRY	3 1 4 2	3 1 3 2	2 2 3 2	3 1 4 2	4 1 3 2			4 1 4	4 2 2 2	2 1 2 N	3 1 3 2		2 1 4 2		1					3 1 4 2					3 1 2
18 SPECTROPHOTOMETRY	2	X	1 3 2 2	1 3 2 2	1 1 2			2 2 2 2	2 1 2 2	1 1 1	2 3 2 2	1 1 1 2	2 2 4			2 3 2 2	2 3 2 2			2 3 2 2	2 3 2 2	2 3 1 2	2 3 2 2	2 1 2 2	
19 FAR ULTRAVIOLET RADIOMETRY	2 2 3 1	2 3 3 2	?	2 2 2 2	4 2 2 2			2 2 2 2	2 3 3 2	2 2 1	2 3 3					2 2 1 2	2 2 1 4					2 3 1 4		2 2 1 4	
20 OPTICS	2 1 2		2 2 1	3 1 3	3 1 2	1 1 N		4 3	3 1 1	4 3	4 1 2	1 1			2 1 2		1	4 4	4 2		4 4	2 1 3	2 1 1	1 1	
21 LASERS	4 3	4 2	4 3	4 2 4	4			2	4 4	4 4	4 4	1 3 1	1							4 2 4	4 2 3	3	3		
22 PHYSICAL PROPERTIES OF ATOMS & MOLECULES	3 4 3			2 2 2	3 4 4					3 4 2	3 4 2						3 3 3			3 4 2					
23 SURFACE PROPERTIES	4 1 3 2		3 1 2 2	3 2 2 2	3 2 3 2			2 2 1 2		3 2 3 2	3 2 2 2						3 2 3 2	3 2 3 2		3 2 3 2	3 2 3 2				
24 IONIZING RADIATION	2 1 3	3 2 4 2	3 3 4 3	3 1 4 3	4			3 3 3 2	3 3 4 3	3 2 3	4 3 4 2	4 3 3 4	2 2 3 2			2 2 2 1	2 2 4 2	4 3 2 4		2 2 4 3		4 3 4 4	4 4 3 3	4 3 4 2	1 1
25 AVERAGE	3 1 3 1	3 1 3 2	3 1 3 2	3 1 3 2	3 1 4 1	3 1 1	4 1 2 2	3 1 3 1	3 2 2 1	3 3	3 1 3 2	2 1 1 1	2 1 2 2	4 1 2 1	1	2 2 1 1	2 2 2 2	4 2 2 2	2 1 2 1	3 1 2 1	4 1 2 1	4 2 2 2	4 3 1 2	4 3 2 2	2 1 1 1

KEY TO MATRIX ENTRIES

C - IMPORTANCE OF TRANSACTIONS

1 = Purely convenience
2 = Strongly desirable
3 = No real alternatives
4 = Essential

D - (IN)ADEQUACY OF SERVICES

0 = No improvements needed
1 = Could be improved
2 = Marginal
3 = Serious deficiencies
4 = Out of control

USERS

C	D
	A
B	R

B - RATE OF CHANGE

N = Declining
0 = Stable
2 = Growing
4 = Growing explosively

A - MAGNITUDE OF TRANSACTIONS

0 = Trivial
1 = Minor
2 = Moderate
3 = Important
4 = Major

R = Flow of requirements info dominates

? = Unknown, X = Not studied, Blank = 0

NBSIR 75-943
TRANSACTIONS MATRIX DESCRIPTION OF THE NATIONAL SYSTEM OF PHYSICAL MEASUREMENTS

Raymond C. Sangster
NBS Institute for Basic Standards
March 1976

EXECUTIVE SUMMARY

Direct measurements transactions matrices have been developed to describe the U.S. national system of physical measurements. Three primary axes have been used: A. *Suppliers* of measurement information, goods, or services. B. *Users.* C. *Measurement Sectors* (kinds of measurement quantity) being described. These three axes define three different kinds of matrices: I. The matrix for a *given measurement sector*, showing the exchanges of measurement information, goods, and services between suppliers and users in that sector. II. The matrix for the *inputs to a given user sector*, from all of the different supplier sectors, for all of the measurement sectors. III. The matrix for the *outputs of a given supplier sector*, to all of the user sectors, for all of the measurement sectors. A summary supplier-user matrix has been generated by summing over all of the physical measurement areas studied, plus use of independent economic data.

Semi-quantitative estimates are entered in the intersection boxes in the matrices for the following quantities: (a) Magnitude of transactions involved. (b) Rate of change of that magnitude. (c) Relative importance or criticality of transactions, independent of magnitude. (d) Adequacy of transactions. Basically, a five point (0-4) logarithmic scale has been used; a change by one unit correlates approximately to a change in magnitude, for instance, by a factor of three. Most estimates of these code entries have been made on the basis of intuitive, informed judgment. Approximately speaking, there is one chance out of three that any given estimate is improper -- either too high or too low. Zeros have been suppressed in these tables, so that a blank box means an estimate of a negligible transactions magnitude.

The measurement sectors studied are these:

Time and frequency
Length and related dimensional measurements
Vibration and shock
Surface finish
Mass, volume and density
Force
Fluid flow
Pressure
Temperature
Humidity and moisture
Thermodynamic properties of fluids
Cryogenics
Electricity
Electromagnetics
Medical ultrasonics
Acoustics
Radiometry and photometry
Spectrophotometry
Far ultraviolet radiometry
Optics
Lasers
Physical properties of atoms and molecules
Surface properties
Ionizing radiation

The supplier and user sector lists have been defined to be identical. As a result, all of the intra-sector transactions are explicitly accounted for, in the diagonal elements of the supplier-user matrices, and all of the user needs information feed-back transactions between the users and suppliers of goods and services are entered. Standard Industrial Classification (SIC) categories have been used whenever possible. The supplier-user categories employed are the following:

Knowledge community
International metrological organizations
Documentary standardization organizations
Instrumentation industry
NBS
Other U.S. national standards authorities
State & local office of weights & measures
Standards & testing laboratories & services
Regulatory agencies
Department of Defense
Civilian federal government agencies
State and local government agencies
Industrial trade associations
Agriculture, forestry, fishing; mining
Construction
Food, tobacco, textiles, apparel, lumber, furniture, paper, leather
Chemicals, petroleum, rubber, plastics, stone, clay, glass
Primary & fabricated metal products
Machinery, except electrical
Electric and electronic equipment
Transportation equipment
Transportation and public utilities
Trade, retail & wholesale; insurance, finance, real estate; other services; printing & publishing
Health services
General public

NBSIR 75-948
ECONOMIC ANALYSIS OF THE NATIONAL MEASUREMENT SYSTEM

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July 1976

EXECUTIVE SUMMARY

The first part of this study deals with the concept of measurement for economic analysis, the qualitative dimensions of measurement in the economy, and the relationship between measurement and economic change. Measurement goods and services yield benefits to users by extending the physical, human senses in providing information about the properties and characteristics of physical objects and phenomena. Measurement information is ubiquitous in the economy; it is used as an input at the interface between buyers and sellers. The making of measurements is resource using, the instruments, labor, and other resources needed to make measurements each have their costs and these costs represent the total cost of the national measurement system. The National Bureau of Standards has begun to study the macro economic dimensions of the national measurement system, and one approach in this study is a measure of the cost of labor and equipment used for making measurements. The cost of these resources used in making measurements was estimated at $36 billion or 6% of GNP in 1963. Each of the 78 major industries studied incurred substantial expenditures for measurement equipment and labor in 1963. Industries that have experienced the most rapid rates of growth and productivity advance also tend to be measurement intensive, i.e., measurement expenditures are high relative to value added by these industries. The Metric Study by the National Bureau of Standards also provided insight into the macro economic dimensions of the transition to the metric system. The cost of conversion to the metric system over the period 1970 to 1980 was estimated to equal 10% of the total cost of measurement in the economy in those years.

The second part of the study examines the measurement system from the standpoint of the private sector, including the economic rationale for measurement by producers, consumers, and in exchange between producers and consumers; and case studies of the costs and benefits of measurement in the private sector. While it is impossible to analyze the benefits of the total national measurement system, it is possible to examine benefits and costs of marginal changes in the measurement system. For example, it is estimated that improvements in the accuracy of moisture meters used in producing corn could save farmers from $194 to $285 million per year. Improved measurement can also yield significant benefits to consumers. X-rays and other ionizing radiation are widely used for both treatment and diagnostic purposes, yet only 65% of the hospitals surveyed proved to have tumor dosage within an acceptable range of accuracy, and 34% of dental x-ray machines inspected were in violation of safety standards. Improved measurement in sales transactions not only improves efficiency, but also results in more equitable transactions. For example, an improvement of only 0.1% in the accuracy of pipeline gas meters would reduce the uncertainty of gas transferred equal to $1,000 per day per meter station.

The third part of the study deals with the role of government in the measurement system, incorporating an economic rationale for measurement activities by the public sector, and case studies of costs and benefits of activities by the National Bureau of Standards extracted from the micro studies. Information provided by measurement is a public or collective good to the extent that the information provided by a single measurement can be given to any number of people with no one suffering a loss of the information. The production of measurement information is sometimes characterized by increasing returns; producers of measurement information often use specialized equipment and personnel who make relatively few measurements. The marginal cost of taking an additional measurement likely is less than the average cost, and the cost of disseminating the measurement information from one person to another is probably trivially small compared to the cost of making the initial measurement. Finally, measurement is accompanied by external economies in such areas as consumer protection, health and safety, international trade, and research and development. Under the above conditions the private market system may not allocate resources to the measurement system efficiently and government intervention in the national measurement system may increase the general welfare.

The role of the National Bureau of Standards in the national measurement system is based on provisions in the Constitution and on enabling legislation designed to implement those provisions. This study discusses the costs and benefits of National Bureau of Standards activities in maintaining basic standards, in conducting measurement research and development, and in providing calibration, dissemination, and publication services. The costs and benefits of selected National Bureau of Standards projects are quantified, including large force calibration, time and frequency service, coaxial connectors, standard reference materials for iron and steel, standard reference materials for metals in oil, semiconductor resistivity, and LPG meter calibration. While none of these studies satisfies the conditions of rigorous cost benefit or cost effectiveness analysis they do provide insight into the economic role of the National Bureau of Standards in the national measurement system.

NBSIR 75-949

STRUCTURE AND FUNCTIONS OF THE NATIONAL MEASUREMENT SYSTEM

Raymond C. Sangster
NBS Institute for Basic Standards
June 1976

EXECUTIVE SUMMARY

The National Measurement System consists of all of the activities and mechanisms--intellectual and operational, technical and institutional--that provide physical measurement data to allow the creation of the objective, quantitative knowledge required by our society. This report describes the functional and structural aspects of the System.

Measurement is necessary in conduct of the life of the individual, pursuit of science, operations of society, and employment of technology. Measurements allow human beings to describe, predict, communicate, decide, control, and react in dealing with what is, was, or will be in the physical universe. The process of measurement requires intellectual comprehension of the phenomenon, quantity, or property to be measured; definition of a reference unit in terms of which the measurement will be made; existence of a means of comparing the unknown to be measured with the reference unit; establishment of a physical reference standard which embodies the measurement unit; agreement within the human community on all aspects of the measurement process; and mechanisms to enforce honesty and clarity in measurements.

Our model of the National Measurement System involves five structural levels.

I. Conceptual Foundation of measurement phenomena, quantities, units, and definitions.

II. Basic Technical Infrastructure to provide tools, techniques, and agreements that allow the conceptual system to be reduced to practice.

III. Realized Measurement Capabilities, abilities to measure specific quantities to known accuracies under defined conditions.

IV. Dissemination and Enforcement Network, institutions that disseminate realized measurement capabilities to users and enforce their use.

V. End-use Measurements.

The basic phenomena and quantities to be measured include space or distance, time, mass or amount of matter, electricity, temperature, amount of substance, and luminous intensity. Many subsidiary units are derived from the basic units. The United States uses both its customary "English" system of units and the modernized metric system, SI.

The technical means required to make measurements include both physical hardware and intellectual software. Software aspects include documentary specifications and standards, descriptions of measurement techniques, educational materials, reference data, predictive methods, and the basic recorded knowledge of science. Hardware aspects include transfer and working standards, reference materials, and measurement instruments.

Documentary standards and specifications include international treaties and conventions; Federal and state constitutions; Federal, state and local laws and ordinances; engineering standards; and procurement specifications.

Suitable instrumentation is the one indispensable element in any measurement process. Both physical apparatus and techniques by which it can produce the desired results must be available.

When a given aspect of matter, material, or fabricated product is sufficiently stable, well defined, and of wide enough interest, measurement data that characterize it can become useful as reference data. Existence of reference data takes a substantial load off the operational measurement system, since it eliminates much repetitive measurement. Measurements of unknown systems are often performed by comparison with known systems, using reference data. Such data may also be used to calibrate measurement equipment. Further, properties of materials may be used to define the measurement process itself, as in use of properties of water to define the temperature scale.

Reference materials complement and supplement reference data in the Measurement System. Their function is very similar to that of reference standards, and for some phenomena, such as density, the reference standards are reference materials.

In some measurement circumstances, the volume of data needed may be so large, or the experimental circumstances so inaccessible, that it is not physically or economically feasible to measure all of the desired data. Predictive methods--models of the phenomena being measured--then become an essential element of the Measurement System.

The central core of the Measurement System consists of knowledge or science and of the people who employ it. In some cases,

this central pillar by itself holds the System together.

The institutional elements of the System include the documentary specifications and standardization institutions, the instrumentation industry, central measurements standards authorities, state and local offices of weights and measures, standards and testing laboratories and services, and technical regulatory agencies.

Documentary standardization institutions operate at levels from the international to the individual company or local governmental unit. The major relevant bodies are the International Organization for Standardization, the International Electrotechnical Commission, the American National Standards Institute, the American Society for Testing and Materials, the Department of Defense, and the General Services Administration.

Over 2000 companies have products listed in the current "Guide to Scientific Instruments" [267]. Economic dimensions of this industry are described in an Appendix to this report.

Legal responsibilities for enforcement of justice in the use of weights and measures in our domestic commercial marketplaces lie with the state and local offices of weights and measures; the National Conference of Weights and Measures is the central coordinating unit. Its paid staff and executive secretariat are provided by the NBS Office of Weights and Measures.

Standards and testing laboratories and services function as "miniature NBS's" by providing physical standardization services to specific portions of the National Measurement System. The most highly developed institutional structures are in the military services. The National Conference of Standards Laboratories is a central organization here. The NBS Office of Measurement Services provides its central secretariat.

Promulgation, enforcement, compliance, and adjudication with respect to the regulatory actions of technical regulatory agencies require a substantial measurement base and comprise a significant portion of the System, making the regulatory agencies the newest recognizable institutional structural element of the System.

The National Bureau of Standards is the primary authoritative central measurement standards institution in the United States. Its calibration and related measurement services provide access to the national standards of physical measurement; it operates the National Standard Reference Data System and provides Standard Reference Materials; it provides coordination services to the System through such Offices as those of Weights and Measures, Measurement Services, and Radiation Measurement, and through the Standards and Applications Division, the Office of International Standards, and the Office of International Relations; and it provides a variety of information services. Historically, NBS has served the Nation in three primary roles, related to measurements, standardization, and technological development. Today, its technological development role is limited to a few specialized areas, and its role in standardization is that of facilitator to other interests. It is in the field of measurements that its role is unique in this country; if NBS did not exist, it would have to be invented. The NBS operating budget comes from direct appropriations by Congress, user reimbursements for routine services, and funds transferred from other operating agencies to cover the costs of special technical services. A series of evaluation panels established by the National Academy of Sciences supports the Bureau management in optimizing the NBS program.

The U.S. National Measurement System is embedded in and part of an international measurement system, for which the International Bureau of Weights and Measures (BIPM) is the central institution. Collective and bilateral interactions among the various national standards laboratories comprise the balance of the institutional aspects of this system.

The major trends of our National Measurement System can be described under the headings of increased complexity, increased integration, improved quality control, improved information resources, automation, metrication and science. The development of the information economy and the rising tide of complexity, confusion, and "noise" in our society both imply increased pressures on the Measurement System to produce exactly the measurement data needed, with exactly the required precision, no more and no less. Increased integration of the System is required to improve its ability to provide most economically and effectively this needed measurement data. Improved quality control, through such mechanisms as the NBS Measurement Assurance Programs, goes hand in hand with the previous two points. Automation is vastly expanding the technical power of the System, by removing barriers associated with limitations of the human hand and mind. Passage of the Metric Conversion Act of 1975 recognizes a major trend in the System, which will have a permanent impact on this country. The scientific developments of the past quarter century have put us in a position to nearly realize the dream of the founders of the metric system, namely a universal system for physical measurements founded on natural law and a single constant of nature.

NBS SP 445-1
THE NATIONAL MEASUREMENT SYSTEM FOR TIME AND FREQUENCY

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May 1976

EXECUTIVE SUMMARY

The major purpose in studying the National Measurement System for Time and Frequency was to determine who uses time and frequency, how they use them, and what their use means to society.

The system is viewed from three vantage points:

1. The *instrumentation* that provides sources of time and frequency (T&F).
2. The *suppliers and users* of T&F.
3. The *calibration hierarchies* for T&F sources.

Most of the work of this study went into determining the present status of the system. Historical information was, however, helpful in forecasts of the future and in putting NBS T&F activities into perspective.

Instrumentation. The major types of instrumentation which have served as sources of time and/or frequency over the last 75 years are pendulums, tuning forks, quartz oscillators, and atomic oscillators. Quartz and atomic oscillators are the sources of primary importance today.

The characteristics of precision quartz oscillators, superconducting cavity oscillators, and the major atomic oscillators are given, and some of their areas of application are described. For example, atomic oscillators are shown to be an increasingly important part of the telephone industry and basic science. The National Bureau of Standards has been a central element in the research and development of atomic T&F standards throughout the some 25-year history of these standards. The Bureau has also made some basic contributions to the development of precision quartz oscillators.

Suppliers and Users. A compact description of fourteen basic supplier-user categories is given in matrix form. The relationship between a given supplier and user is specified by two descriptors. One descriptor gives the *volume of use* of a specified time or frequency output. The other gives the *importance* (to an organization's internal operations) of that output.

The majority of the effort devoted to this study of the National Measurement System for Time and Frequency went into extensive studies of eight major areas. They are:

- Standards Laboratories
- Users of NBS Radio Broadcasts
- Telephone Industry and Specialized Carriers
- Military
- Position Location
- Aviation Industry
- Electric Power Industry
- Shipping and Boating Industries

Information gathered in these studies was vital in completing major portions of the T&F flow matrix. The communication and position location industries emerge as two of the most important and sophisticated users of T&F. The matrix indicates the great importance of the NBS standard T&F broadcasts. A current study is increasing our understanding of the users of stations WWV and WWVH. The study confirms that the applications of communications, navigation, and standards laboratories are very important. The three most heavily used aspects of our broadcast services are voice announcements of time-of-day, one-second "ticks", and standard frequencies.

Calibration Hierarchies. The various sources of time and frequency must be compatible with one another to within some specified tolerance. The stringency of this requirement depends on the sources involved and the uses to which they are to be put. The necessary compatibility is often achieved by means of a calibration hierarchy.

There is no legal, technical, or economic force to create a unified calibration hierarchy, and none exists. This is one reason why it is difficult to comprehend the National Measurement System for Time and Frequency. Multiple hierarchies do exist, however, and they are basic to the system. Some of these hierarchies have the force of law and apply across organizational boundaries. Others are voluntary or are only binding within one organization. Those *not* having the force of law usually have the greatest requirements for quality of T&F. To understand why these several hierarchies exist, it is essential to consider cost and ease-of-use as well as quality.

Four major calibration hierarchies are those of the standards laboratories (industrial, governmental, etc.), telephone time-of-day, the military, and the telephone industry. The National Bureau of Standards has been a part of these four hierarchies. It is presently a fundamental part of the standards laboratory hierarchy and telephone time-of-day. It is also an important part of the military T&F calibration system. The National Bureau of Standards' importance to the telephone industry is much less than it was in the past (since the telephone industry is now basing its synchronization on atomic oscillators), but is potentially still important.

The Future. The system appears to be changing in three major ways:

1.) By 1980-85 there will probably be a widespread, low-cost network of clocks that are synchronized in the range of 1 to 10 μs, Today, widespread synchronization, at a cost of a few hundred dollars per site, can only be done to about 1 ms.
2.) By 1980-85 the market for frequency equalization in the range 1×10^{-9} to 1×10^{-11} will probably be quite important. The cost per site will need to be less than about $2000 (in 1975 dollars), and the equipment must be easy to use.
3.) The use of quartz watches and clocks, with digital readouts and the capability of being set to the precise second, will probably be extensive. This may necessitate a widespread calibration network for time-of-day that is accurate to about 0.1 seconds.

The Time and Frequency Division of NBS currently has two programs - T&F dissemination via satellite, and frequency calibration via TV - that address the first two areas of probable change. A third program directed to these frequency equalization requirements, a low-cost, medium-accuracy oscillator, will likely begin soon.

The third area of probable change, if it occurs, will be more of an economic than a technical problem. As such, it would not likely increase the demand for NBS resources with regard to time-of-day.

Conclusions. This study of the National Measurement System for Time and Frequency clearly demonstrates that NBS has an important and unique role in the system. The question is not whether there are desirable alternative sources for the services presently rendered, or whether these services are in fact needed. It is instead whether NBS can perform its function more economically and effectively. Experimental broadcasts of standard T&F via satellite and other developments indicate that it can do both.

The NBS T&F services have been, and are, and should be, in the nature of what economists call a "collective good". This is a "good" (product) which is clearly of social value but one for which a fair market price is difficult to determine. It is interesting to note however, that there is now a *minimum* of one million dollars worth of special-purpose receiving equipment in the field. This equipment was specifically designed to receive the broadcasts of WWV and WWVH or WWVB. Also, if $0.05 per call were received for the *NBS* telephone time-of-day service this would generate a revenue of $50,000 per year.

One of the most general things that emerges from the entire study is that time - and its ever-present companion, frequency - are the great coordinators, the great organizers. Almost any activity today that requires precision control and organization rests on time and frequency technology.

(A diligent effort has been made to make this report comprehensive and accurate as of March, 1975. Since that time no important changes or additions have been made. There have, however, been a few significant changes in the National Measurement System for Time and Frequency. The interested reader may wish to contact the author for his opinions on these changes.)

NBSIR 75-926
THE NATIONAL MEASUREMENT SYSTEM FOR LENGTH AND RELATED DIMENSIONAL MEASUREMENTS: PART 1

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March 1975

EXECUTIVE SUMMARY

The determination of length and related dimensional measurements constitute the largest group of measurements made in science, manufacturing, and technology. It has been estimated that 80% of all measurements made in industry are of length and displacement. Figures developed from our recent study of the National Measurement System shows that an average of $9.4 billion is expended annually by the manufacturing sector alone to perform dimensional measurements in our economy.

Length and related dimensional measurements have impact upon many areas of the economy. The largest area is in manufacturing and within manufacturing the first-order impact areas are air frames and aircraft equipment, ball and roller bearings, car accessories, domestic appliances, electronic equipment, gears, general engineering, geodetic investigations, integrated circuit industry, photogrammetry, research and development, screwthread industry, scientific instruments, and watches. In many of these areas dimensional measurements are made to satisfy functionality requirements and little else. For example, the parts of an automobile engine would not fit properly if they were measured with different micrometers which were not accurately calibrated.

In the course of our National Measurement System study in Length and Related Dimensional Measurements, we have established over one hundred and fifty contacts with individuals within governmental agencies; industry; professional societies and organizations; scientific and trade journals; and universities and colleges around the nation. Many of these people contacted were surprised that we were willing to listen to their problems in dimensional measurements. In almost all cases, the organizations contacted expressed a keen desire to continue the dialogue established between the Bureau and their personnel.

The primary industrial contact was within Standard Industrial Classification 3548, Machine Tool Accessories and Measuring Devices. This industry was expanded into further prouct codes such as 35452, Precision Measuring Tools; 3545211, Comparators; 354221, Gage Blocks; etc. In many cases the contacts expressed no pressing need for any greater accuracy in standards for dimensional measurements. For example, the accuracy inherent in various dimensional artifacts (gage blocks, etc.) and instrumentation (laser interferometers, etc.) far outpaces the ability of many to transfer displacements obtained from these devices to other objects. (This is verified by viewing the results of some recent surveys contained in our report illustrating inconsistencies of 0.00177mm to 0.00254mm-70 to 100 microinches-in the measurement of internal diameters of finely finished ring gages.

The primary users of the National Bureau of Standards' most accurate dimensional measurements are the Department of Defense Primary Standard Laboratories, the various gage and measurement instrument manufacturers, and the private standards laboratories including those who only service the parent organization.

Another major user category of NBS services is the machine tool industry. In the recent *U.S. Industrial Outlook 1973*, the machine tool industry ranked first in percentage increase in value of shipments from 1972 to 1973 (27 percent increase from $0.825 billion to $1.050 billion). An increasing percentage of manufacturing is being done under numerical control (NC). NC machine tool shipments are growing three times as fast as conventional machines and it is estimated that 15-20% of U.S. metalworking machine tool shipments are currently NC. There are pressing needs to develop standards and algorithms to characterize the accuracy of these machines. The reason for accurate calibration of NC machines is that the accuracy of parts produced is 100% dependent on the inherent positioning accuracy and geometry of the machine tool.

The areas of surveying and geodetic investigations are frequent users of NBS calibration facilities (tapes). In recent years calibrations have been steadily declining and the 1974 NBS calibrations in this area were only approximately 20% of the same services in 1971. We have found that with the recent advent of relatively inexpensive electronic distance measuring devices, many companies and individuals are now able to afford these devices.

We had initiated steps to interact with the machine tool industry to a greater extent even to the point of obtaining compli-

mentary exhibit space in the International Machine Tool Show (IMTS) in September 1974 in Chicago. The specific purpose of our exhibit was to listen to and view first-hand some of the measurement problems within this important area. Four hundred and sixty-one people requested 1300 copies of the various dimensional technology and optics and micrometrology reports. The majority of these reports are the "how we do it" type.

One fact has been repeatedly borne out from all contacts--the need for more awareness of the work being done at NBS and the need for more publications at multilevels discussing how to make accurate and precise measurements.

The results of the recent NCSL audit package measurements show the need for dimensional artifacts to verify the accuracy and precision of industry's gages and measurement system other than the standard set of gage blocks, angle blocks, plug and ring gages, spheres, etc. NBS should develop these standards and make them available to the various laboratories for their use to determine the accuracy and precision of their measurement system. In addition NBS should develop, in conjunction with industry, a three dimensional artifact to be used to determine the accuracy of their three dimensional measuring machines as well as their complex NC machining centers.

NBSIR 75-926
THE NATIONAL SYSTEM FOR LENGTH AND RELATED DIMENSIONAL MEASUREMENTS, PART 2: MECHANICAL VIBRATION AND SHOCK

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August 1975

EXECUTIVE SUMMARY

The technical areas of mechanical vibration and shock are examined within the framework of this National Measurement System Study. Manufacturers and users of vibration test equipment were contacted to ensure that an accurate as possible assessment was being made. Of special interest are areas where vibration measurements are assuming more importance to the nation. This investigation sampled the manufacturers and users of vibration equipment to determine the true nature of the vibration and shock infrastructure. The scope of this study includes the following mechanical motion parameters: The principal dynamic vibration parameters are displacement, velocity, and acceleration. Parameters of secondary interest to this study are dynamic force, mechanical impedance, damping, and transmissibility (related to vibration isolation). These secondary parameters are not all discussed in detail, however, they are discussed as they relate to measurements for areas of machine and tire balancing, vibration isolation, and vibration damping.

Vibration and shock measurements are vital to several large and important sectors of the U. S. economy. Testing of military ordnance and other hardware have critical requirements for shock and vibration measurements. The aerospace industry utilizes vibration as a key element in the development and testing of aircraft, rockets and satellites. Rotating and reciprocating machinery require (in some instances crucial) balancing for proper operation. Auto makers must, by Federal regulations, make safety related crash tests. And, household appliances are being subjected to vibration tests to improve their reliability and durability.

The suppliers of vibration and shock measuring instruments, and generating equipment (i.e., vibration generators and shock machines) were analyzed and their number and economic size determined. About 18 of 40 plus companies dominate the market. They have an estimated annual sales of about \$200 million. The suppliers of vibration isolators and damping materials number about 45 of which 8 are considered dominant. Their annual sales are estimated at \$110 million. There are about 32 manufacturers of balancing machines of which 9 are dominant. They have an estimated sales of \$95 million. In an overall composite of the entire number of suppliers included in this study, there are about 42 predominant companies out of a total of 132. The total annual sales are estimated as \$405 million.

The measurement infrastructure for vibration and shock is examined by accuracy needs, types of applications, and amplitude and frequency ranges. Critical applications such as ordnance testing or aircraft development and testing require traceable vibration and shock measurements. These amount to about one-half of all the vibration measurements made. Such measurements often specify uncertainties in the range of ± 5 to ± 20 percent of vibration amplitude and ± 1 to ± 5 degrees of phase. The instrumentation used to monitor these types of tests are usually calibrated by comparing them to standards that the companies or agencies maintain. Ultimately, the standards are calibrated by NBS as reference standards. The measurement infrastructure also includes a large number of less critical vibration measurements, for example, in dynamic balancing rotating and reciprocating machinery. Measurement uncertainty may range from ± 10 to ± 200 percent of the vibration amplitude. In many of these applications, so long as the vibration level is safely below a specified value, accurate measurement need not be supported by a complex traceable chain to NBS. Some measurements within the infrastructure do not even require accuracy whatsoever; only sufficient sensitivity to be able to detect vibration and to be able to measure relative changes in the vibration level. A common example is dynamic wheel and tire balancers. Where traceable vibration standards are needed, the NBS provides a calibration service on a reimbursable basis.

With the exception of shock measurement standards, the vibration standards and procedures are generally adequate for the majority of needs. A comparison shock calibration service is available at NBS with additional refinements required. There is a serious need for absolute calibration methods for shock which are currently being developed. As a result of this study, gaps in the measurement methodology have been assessed in areas of vibration isolation and in damping. Efforts are being directed towards both of these areas.

NBSIR 75-927
THE NATIONAL MEASUREMENT SYSTEM FOR SURFACE FINISH

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August 1975

EXECUTIVE SUMMARY

Surface finish measurements involve the outside surfaces of products, the part which is most evident to the user and which is frequently responsible for the quality of its performance. The average consumer can visually detect less than one millionth of an inch of surface roughness in a highly finished chrome plated surface. The reliability of clock motors, the performance of switches, the effectiveness of razor blades, the safety of a wheel bearing, all of these depend on careful measurements of manufactured surfaces.

The National Measurement System for surface finish consists of the standards, the measurement techniques and procedures, the personnel, and the equipment through which surface finish measurements are conducted in the United States. The purpose of this study was to determine as quantitatively as possible the structure, vitality, integrity and future requirements of this measurement system. The study was initiated by a literature search, followed by visits to instrument manufacturers, industrial laboratories and academic institutions.

Each of the hundreds of metalworking industries has a special surface finish requirement. The highly polished pipes and tanks of the dairy, food and hospital supply industries permit rapid sanitation inspection. Quality of magazine illustrations depends upon the surface finish of gravure plates and cylinders. Automotive safety and reliability is related to the surface finish of hundreds of bearing, seals, brake drums, valves, cylinders, etc. The lifetime of surgical implants is directly related to their surface finish. Military applications abound. The list is endless. Yet, each application requires different surface micro-features. The most important conclusion of this study was that NBS should develop measuring procedures and methods for analyzing surface profiles so that each metalworking industry can properly inspect its surfaces according to its needs.

The second most important measurement need is for instrumentation capable of measuring new, high technology surfaces such as integrated circuits, computer discs and drums, surgical implants and precision bearings. New molecular electronic devices require surfaces which are smooth on the atomic scale. A third important need is for on-line surface finish measurement in manufacturing processes.

NBS calibrates precision reference specimens of surface roughness (carefully manufactured rough surfaces) according to the voluntary American National Standard B46.1. These specimens provide calibration users with a readily available physical standard to check their instruments. The integrity of the measurement system is maintained by national and international intercomparisons and by direct calibration of users' standards. There are no regulatory agencies in surface finish. NBS also calibrates thin film steps for the microcircuit industry. Since both thin film steps and surface finish measurements are basically length measurements, NBS bases these calibrations on the defined unit of length through interferometry.

The information gathered in this study has already provided a solid basis for management decisions within NBS with regard to the distribution of the very limited resources in the surface program (2 1/3 man years; $84K of NBS funds). For example, first priority has been given to a new calibration facility which includes computer analysis of surface profiles. Second priority is assigned to the development of new, high resolution instrumentation. Work with standards committees also has a high priority.

The study revealed a broadly based need for research leading to an understanding of the relationship between the surface finish and the function of a part. Such a study cannot be underwritten by instrument manufacturers since the 25,000 instruments now in use are very long lived. Yearly sales of the largest U.S. instrument manufacturer amount to only $1 million per year. The metalworking industry spends $54 million yearly in making surface finish measurements on products whose market value exceeds $40 billion. Yet this effort is thinly spread over hundreds of industries, so that little reported research is done. These circumstances have resulted in stagnation in U.S. surface programs relative to government-supported foreign research. NBS is now able to provide measurements and instrumentation to those who wish to pursue such programs in the U.S. Several small cooperative efforts with industry and a university are now underway.

NBSIR 75-928

THE NATIONAL MASS, VOLUME, AND DENSITY MEASUREMENT SYSTEM

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June 1975

EXECUTIVE SUMMARY

Mass, defined as the quantity of matter in a body, is measured by determination of the magnitude of its attraction by the earth via the weighing operation. The mass unit, the *kilogram*, is unique among the Fundamental Units of the *International System* of units in that it is a man-made object-*International Standard Prototype* K-kept at the *Bureau International des Poids et Mesures* (Sèvres). The U.S. unit is defined by the replicas of K *Prototype Kilograms No. 4 and No. 20.*

Volume is a quantity derived from the meter whose unit is the cubic meter. It is inevitably coupled with mass since the most convenient method of measuring volume is to determine the mass of the water the volume contains. The intent of the founders of the Metric System was that one cubic deciliter of water have a mass of one kilogram, although its realization has proven to be imperfect.

Density is a quantity obtained by dividing the mass of an object by its volume and it completes this closely related triad.

Extending from this triad are the force and pressure measurement systems which are themselves subjects of the National Bureau of Standards *National Measurement System* studies.

The chain of national measurement activity extending from the narrow peak of the 10 man-year effort at NBS is staggering. Mass calibrations, a $25,000 a year billed effort, supports a clientele who produce 80 billion dollars of goods and services.

A much smaller effort on the part of the Mass and Volume Section supports the State's Weights and Measures Enforcement activity by way of the coordinating efforts of the Office of Weights and Measures. This effort chains to the corner grocery store where about 84 million weighings a day are performed. These weighings in turn necessitate a 145.1 million dollar a year industry to manufacture the weighing devices needed.

The impact of volume measurements on the economy is equally impressive. Volume measurements are made at all levels of the economy from research laboratories to milk processing plants. This study is concerned with glass and metal containers which form the basis of all volumetric measurements including flowmeters, etc. The 1972 sales for scientific/laboratory glassware and industrial/technical glassware totaled over $154 million of which a large part were devices for volumetric measurement such as burets, pipets, etc.

With the current interest in the petroleum industry, it is interesting to note from figures given at the *9th World Petroleum Congress,* that the petroleum industry has a measurement investment in volume measurement facilities of $1,800,000,000 located at 650,000 sites, manned by 50,000 full-time personnel and that each barrel is measured on the average of 12 times between well head and consumer. A 5% error represents an accounting discrepancy of $65.00 per thousand barrels.

Density, the least appreciated member of the triad, more than holds its own.

Density measurements are used in the petroleum, sugar, milk-processing industries and by the Internal Revenue Service, hospitals and various research laboratories. Density determinations are used for materials identification and sorting, assaying, and manufacturing process control.

One of the most widespread devices for measuring density is the *hydrometer*. The value of shipments of hydrometers rose from $4.626 million in 1971 to over $8.102 million in 1972. NBS services the national measurement system for density through calibrations of manufacturer's and many large user's master hydrometers. Six million dollars are expended annually by various users (manufacturers of beverages, industrial chemicals, grain products, sugar, and electronic components) to perform density measurements, predominately using hydrometers. This figure fails to illustrate the full impact of density measurements. For example, in the beverage industry, approximately $2.5 million is expended annually for density measurements in an industry having a total value of shipments of over $15.4 billion in 1973. A properly calibrated $15 hydrometer can often save a company thousands of dollars in federal fines.

Despite the enormous leverage of the Mass Measurement system, it appears to be in almost complete control and operating to the satisfaction of all concerned. The happy technical situation arises from the facts: (1) that mass standards are intrinsically stable so that the unit once injected into a subsystem remains consistent; (2) the instruments used are reliable; and (3) the traditional Weights and Measures activities stabilize the system since the available measurement precision exceeds the needs of trade and commerce considerably. The result is a mature measurement system which has been stable in the recent past and which can be confidently predicted to remain so in the foreseeable future. The origination and development of *Measurement Assurance Programs,* which are programs designed to allow NBS or any other interested party to test the effectiveness of measurement subsystems relative to their intended use, provide a running audit of the system to insure that this stability is not lost.

This study revealed only minor flaws--the correction of which will form the basis of the future program at NBS.

In mass the most immediate and closest to home flaw lies in the first transfer from the prototype kilogram. The definition of *mass equality* calls for balance in a vacuum environment--the density of the objects plays no role. In practice, weighings are performed in air where a density dependent air buoyancy correction must be applied. This buoyancy correction between the platinum prototype kilogram and the weights of every day use amounts to about 80mg in a kilogram. Recent studies lead us to believe the correction used by all national laboratories may be in error by the order of 1%. This error, if confirmed, means that the mass scale of commerce is offset from the defined scale by as much as 1mg at the kilogram level. The offset is too small to affect the consistency of the U.S. mass scale compared to the rest of the world, but it is of importance for fundamental physical constants and must be resolved.

Further down the dissemination chain, there are problems of a political nature generated by the United States' recent joining of the *International Organization for Legal Metrology*. This is a treaty organization and the U.S. is "morally obligated" to adopt its standards which conflict in some instances with U.S. practice. The *National Conference of Weights and Measures*, the principal mechanism for NBS influence on States' Weights and Measures activities has expressed serious misgivings over the U.S. position and has raised questions which must be resolved.

With respect to *volume*, our recent study found the need existed for a good volume standard for high pressure, large volume gas meters. Companies are currently using an awkward transfer process from a cubic foot standard calibrated at NBS to a larger cubic foot bell prover to specially constructed rotary meters. The main impact would be on the metering industry.

In the clinical laboratory user area, we found a desire by various individuals to participate in the development of uniform standards for the calibration of certain volumetric dispensing devices. The standards for measuring the delivery of a pipet are cumbersome and not applicable to check or calibrate many of the relatively new automatic diluters or dispensers which have been marketed in recent years for clinical laboratory use. One particular laboratory which is heavily automated estimates that 1% to 2% of their tests are repeated "due to error created by inaccuracy in diluting or dispensing of samples of reagents". Clinical laboratories are one of the most rapidly growing service industries having increased sales from a level of $1.5 billion in 1965 to an expected $7 billion in 1975. Reduction of the number of repeated tests represents a cost savings to hospitals and to patients.

Density measurement appears to be in control except for research in the areas of fundamental constants and oceanography. Commercial and industrial needs for accurate density determinations are being satisfied by commercially available instruments. Density measurement precision has been limited by the uncertainty in the density of water to about 10 ppm. Recent work at NBS on solid artifact density standards has reduced density measurement uncertainty associated with reference standards to 1 ppm. Dissemination of this accuracy is in progress.

A need was identified in the beverage industry for in-line density measurements for process flow lines. In-line density measurements are expected to increase manufacturing efficiency. A recently developed instrument, now commercially available, satisfies this need and is being used by portions of the industry.

The above listed flaws, notwithstanding the NBS responsibilities in the area of mass, volume, and density, are judged to be satisfactory and the level of effort now deployed is deemed to be correct in magnitude. The course of NBS activities for the future lies in the correction of these flaws and in the continued maintenance of the current system.

NBSIR 75-929

THE NATIONAL FORCE MEASUREMENT SYSTEM

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June 1975

EXECUTIVE SUMMARY

This study outlines the detailed structure of the National Measurement System as it pertains to force, and assesses the economic, social, and technological impacts of force measurements in the United States.

Force, as a unit of measurement defined by Newton's Second Law of Motion, is derived from the basic units of mass, length, and time. The most precise standards of force are realized in deadweight calibration machines such as those maintained by the National Bureau of Standards, a few government laboratories, one commercial calibration laboratory and a few industrial metrology organizations. The deadweight facilities at NBS are widely accepted as the national standards of force.

In practice, deadweight machines are used to provide a few precisely known forces for the calibration of high quality force transducers such as load cells and proving rings. These secondary standards are used to calibrate the multiplicity of devices for field measurements. Accuracy requirements in the measurement system range from the 0.002 percent accuracy of primary standards to about 10 percent for rough measurements such as crane overload indicators.

Force measurements are often contractual in nature. This is true whether the measurement is a strength of materials measurement made in a testing machine or a weight measurement made at the local supermarket or in a railroad freight yard. As a result, the social and economic impacts of force measurements are very diffuse, even to include the entire goods fraction of the economy. While the greatest number of force measurements are made in the metals and textiles industries, this diffusion tends to make force measurements almost invisible. So many measurements are made that each one costs very little. For example, the impact of a single, well defined measurement is cited. Federal regulations require that every eyeglass lens be proof tested before being used. The lens manufacturers pass on to the consumer the $1.00 per lens cost of the test. When you realize that about 100 million Americans purchase about 200 million pairs of glasses and sunglasses each year, the direct consumer cost of that one measurement is quite large. The contractual nature of force measurements is often the "raison d' etre" of force measurement standards. Such a standard, almost always a voluntary agreement upon the method of test to be used, gives confidence to the buyer and seller that an equitable business agreement has been reached. This confidence is a non-measureable, economic, social-technological, impact of force measurements. If the standards of force measurement did not exist, the cost of doing business would increase to cover the cumulative uncertainties resulting from inaccurate measurements.

The history of NBS and of force measurement in this country are closely linked, beginning in the 1830's with the distribution of mass standards by the Office of Weights and Measures, and continuing today, with the development of proving rings, deadweight machines, and load cells and test methods. In addition NBS has participated in the formulation of many of the measurement test methods now in use. The role of NBS at the primary standards level in the measurement system is to provide adequacy, stability and consistency to the system. No other organization is so uniquely placed to provide that function.

The best assessment of the National Force Measurement System is that, while some aspects of it are stable and adequately maintained, other needed parts of the system scarcely exist. The historical areas of effort in static force measurement, over the range from 0.5 newtons (0.1 lbf) to 5×10^7 newtons (1×10^7 lbf), are fully adequate with the level of accuracy now provided and will remain so for the foreseeable future. They require only continued routine support and maintenance. In the areas of dynamic force, very small static forces, information transfer and metrication, however, the measurement system shows serious weaknesses. The measurement system for dynamic force does not exist. The standards and test methods that are needed to assure the accuracy of dynamic measurements and the reliability, efficiency and safety of load carrying systems under dynamic conditions such as impact and fatigue are not available. A similar condition exists for the measurement of very small forces down to 10^{-7} newtons (10^{-8} lbf). Measurements in this range are needed in such areas as biomedical research and ultrasonic, nondestructive testing of manufactured parts.

The information transfer sector of the system is quite cumbersome. This is a result of the diversity of groups performing force measurements. In conjunction with the adoption of a new method for the calibration of force measurement devices, the system is now beginning to establish the lines of information return from the end user to the source of primary calibration. NBS is actively promoting this exchange through round robin calibration of devices and by measurement workshops.

The anticipated metrication of force measurements has become an area of increasing concern. In the field of force measurements, the foreseeable problems of education of professionals and large, long-lived capital equipment, have been compounded by the confusion about the unit of force which will evolve in common usage. The SI unit of force is the newton. However, European common usage is the kilogram-force. This usage has evolved in much the same way as the pound-force unit did in the U.S. This confusion will delay the acceptance of the SI unit and, as a result, force may be one of the last SI units in common usage.

This study has served to verify many of the current concepts of the condition of the force measurement system. Several strengths and weaknesses have been discovered and studied. NBS, through its standards and calibration activities will continue to have a stabilizing and unifying effect on the system. NBS should increase its efforts in areas of the system where weaknesses have been found.

NBSIR 75-930
THE NATIONAL MEASUREMENT SYSTEM FOR FLUID FLOW

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August 1975

EXECUTIVE SUMMARY

Fluid flow is a diverse field concerned with the motion of a wide variety of fluids encountered both in daily life and in scientific applications. It encompasses movement of weather systems by atmospheric winds, travel and dispersion of air pollutants, flow around aircraft and spacecraft bodies, oil and gas pipeline flow, irrigation and waste water flow, and many others. The types of fluid motions encountered in descriptions of these phenomena include closed-conduit, open channel, supersonic, subsonic, steady, unsteady, laminar, and turbulent flow. Measurements of the properties of these flows are instrumental in the functioning of the nation's industries and the advancement of scientific technology, and impact the lives of every consumer.

This report presents the concept of the National Fluid Flow Measurement System as it exists today and the activities and mechanisms it employs to generate and implement measurement data. The system structure is presented, and data and information gathered on the interrelationships between the identifiable parts are reported. To further the study, more than 200 contacts were made with trade associations, government agencies, private companies and universities.

The basic structural element of this measurement system is the combination of the fundamental units of mass, length, and time to describe fluid response to external forces. Such responses are generally velocity (m/s), mass flow rate (kg/s), or volume flow rate (m^3/s), but can include specialized quantities like Mach number and frequency of flow fluctuations. Also affecting this response are the inherent fluid properties, such as viscosity, density, thermal and electrical conductivity, and bulk modulus of elasticity.

Documentary standards for fluid flow measurement represent international, national, and commercial viewpoints, and are used voluntarily by all parties. International organizations such as ISO and IEC are active in fluid flow preparing measurement standards, meter performance standards, and recommended practices for making measurements and analyzing errors. Nationally, ANSI, ASTM, ASME, API, and AGA prepare similar standards for flow measurements commonly encountered in their application areas.

Measurements are made with a variety of tools, some of which have been in use for a great many years, and others which are innovatively new. These instruments operate on a variety of principles including differential pressure, force, convective cooling, sound transmission, electromagnetic effects, vortex shedding, and more recently light scattering. In particular, vane and cup anemometers, water current meters, and orifice flowmeters are among the most commonly used meters in meteorology, stream flow measurements, and pipeline flow measurements respectively. A rapidly growing area of new instrumentation includes sonic anemometers, laser velocimeters, and electromagnetic meters, the latter being used in conducting fluids such as liquid metals, wastewater and water under certain conditions.

Current capabilities, facilities and ranges of services of numerous calibration and standards laboratories engaged in gas and liquid flow measurement are identified. These include:

(1) Air flow
- 80,000 scfm, 2800 psig at the Colorado Engineering Experiment Station
- 3,000 scfm, 125 psig at NBS
- 2 to 150 mph at NBS

(2) Water flow
- 40,000 gpm, 21 psig at Alden Research Laboratory
- 10,000 gpm, 75 psig at NBS

(3) Liquid hydrocarbon flow
- 10,000 gpm, 40 psig at Brooks Instrument Division
- 2,000 gpm, 50 psig at NBS

Additionally, over 60 instrument manufacturers have been identified that are traceable to NBS through calibrations submitted over the last seven years.

The study indicates a trend of U. S. domestic business in which total sales dollars have increased for fluid flow measurement equipment from \$67.2 million to \$123.8 million in the period 1963 to 1973. The annual volume continues to grow with mounting demands for accuracy and sophistication of equipment. In testimony before the Congress, the manufacturers of scientific instruments testified that about 25 percent of the annual value of flow meters and instrumentation sold by the industry is sold abroad. They believe that these export sales exceed imports by more than four to one, and they are the leverage for export sales of instrumentation and control systems valued at twice to three times the flow measurement products.

State-of-the-art changes and technological advancements in fluid flow include both improvements in traditional instrument designs and numerous new designs that are finding increased application. Inflated fluid resource values and increased operating costs in fluid transportation are forcing a general rise in the cost to flow a unit of fluid. Subsequently, greater investments are being made in increased measurement reliability and accuracy and in the managing and controlling of fluid flow. Primary metering devices are becoming increasingly sophisticated. In general, the applications which impose the most urgent requirements on flow measurements are those which stem from the imposition of new Federal regulations in fields that include environmental air and water quality control, coal mine health and safety, occupational safety and health, and clean room and work station requirements. Implementation of these regulations will increase the requirements for consistent and reliable measurements of many flow quantities that cannot be measured adequately today.

Specific fluid flow measurement needs are identified that include: providing new flow standards, preparing recommended practices, and evaluating and developing instrumentation for the measurement of low velocities and unsteady speeds of air; reducing the uncertainties in values of discharge coefficients for orifice meters; and providing new flow standards, preparing recommended practices for in-place applications, and evaluating and developing instrumentation for the measurement of velocities and flow rates of supply water and waste water. A general trend has been discerned underlying these needs in which opportunities to implement measurement assurance and the transfer-of-measurement capability are becoming increasingly important.

NBS functions as an integral element of the fluid flow measurement system, conducting fluid mechanics research and development, contributing to flow standards, and generating engineering data on a variety of flows. Calibrations are offered for instruments to measure velocity and mass flow rate in air, water, and liquid hydrocarbons. NBS services impact government agencies concerned with health, safety, power, fuel resources, water resources, weather monitoring, pollution control, and military and space programs as well as major segments of private industry such as the oil and gas industry, power utilities, heating and ventilating, and transportation. These user classes share a common concern for adequacy, accuracy and reliability of the various aspects of flow measurement.

Fluid flow measurement technology today represents a constantly changing field, thus supplying the impetus for a number of improvements within the National Fluid Flow Measurement System. In particular, a need for a national fluid flow reference system was emphasized at the 1974 NBS Flow Measurement Conference. This need is underscored by discrepancies in flow calibration results, duplication of measurement efforts, the lack of a technical "third party" to arbitrate discrepancies in measurement, and the lack of facility certification.

New measurement capability is also needed in both the very small and very large rates of flow. For example, the automotive industry is targeting for fuel flow calibrations at approximately .08 g/s with $\pm$ 0.2 percent accuracy. Also, very low velocity measurements are required in air and water flows in order to meet regulatory requirements being established for health, safety, and environmental quality. The nuclear power industry requires measurement of cooling water flows on the order of 60,000 - 120,000 l/s per minute, depending on plant power output. Such Such plants also must be capable of measuring 150 C condensate flows of 1,200 l/s with accuracies of 0.1%. Additionally, limited natural resources and increased competition for fresh water between power generation utilities, industrial users, and agricultural water suppliers requires improved accuracies of field measurements.

To meet these needs, the NBS fluid flow program includes extension of measurement capability with emphasis on flow ranges encountered in new regulatory acts, error analysis in field measurements, meter performance evaluation for improved accuracies, and maintenance of contact with the user community through conferences and correspondence.

NBSIR 75-931
THE NATIONAL MEASUREMENT SYSTEM FOR PRESSURE

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April 1975

EXECUTIVE SUMMARY

The field of this study is the measurement of pressure and vacuum. This field has developed from humble beginnings in the laboratory of Evangelista Torricelli in 1644 to one that encompasses practically all manufacturing processes, the operation of many types of machines, important scientific endeavors and our daily life. Industrial applications cover 17 decades of pressure and science adds another five. Within its range are billion-dollar industries using pressure or vacuum in a significant way to make or control semiconductors, radiators, beer cans, aircraft, automobile tires, missiles, freeze dried food, power plants and many other products or manufacturing activities. Savings of great economic significance can be achieved through accurate measurements of pressure. The safety of aircraft and of nuclear reactors is ensured through, among others, pressure measurements.

A significant part of the measurements in this system are referred to NBS primary standards mainly through the instrumentation industry. NBS calibration services now cover about five decades of pressure and an expansion to seven decades is planned for the near future. The calibration services are based on a number of primary standards, whose accuracy and precision are adequate for most purposes and work continues to update and improve these standards. The dissemination of accurate measurements into the field is not always satisfactory. Large uncertainties added in the calibration chains are due to inadequate technical and mathematical procedures, lack of good transfer standards and lack of training of the personnel involved. The calibration services are backed up by training of industrial personnel, preparation of technical manuals and reports, data evaluation service, laboratory evaluation service and extensive consultations. All of these back-up services were prompted by early results from this investigation.

The field of pressure measurements is currently undergoing rapid changes through the introduction of new types of measuring instruments, through an expansion of the range of pressures used in industry and through the requirement for lower uncertainties. There is close cooperation between NBS and the professional and engineering societies on the development of the necessary measurement standards and test codes. Increased awareness of possible safety problems with gages and transducers, and particularly with high pressure vessels was prompted by the Occupational Safety and Health Act. Here again NBS is cooperating with the concerned parties to provide the necessary engineering standards. All of these activities tend to lead to an infrastructure that is more strongly focused on the primary standards of pressure at NBS and the related dissemination services.

A critical need, involving the safety of people, is felt in the pressure range required for the calibration of aircraft altimeters. No central standards are presently available to ensure uniform measurements throughout this country and the rest of the world in this important range. A new standard is, however, under construction. Also, a measurement assurance program is under study to bring this area under control. Similar problems appear to exist with the nuclear breeder reactor program and measures to bring this under control are being discussed.

A Delphi technology forecast was undertaken to determine the need for vacuum measurements, which are not provided by NBS. This study is not complete, but it has provided valuable information for planning and management decision making. Of approximately 125 randomly selected members of the American Vacuum Society, 68% stated that they require vacuum calibrations in the range 10^{-1} to 10^{2} Pa with an uncertainty of 0.1%, or better, now. 42% now require vacuum measurements to better than 1% in the range 10^{-7} to 10^{-4} Pa. A much larger percentage of experts in various fields of vacuum measurements foresee these needs for the immediate future. The most demanding requirements for vacuum measurements were found in the manufacture of semiconductors, in the space industry and in the vacuum instrumentation industry for the calibration of standard leaks and the measurement of pumping speeds. It is not surprising that in these industries, which represent a production volume of more than $6 billion, the average standards laboratory spends more than $130,000 annually on vacuum measurements. NBS does not maintain any vacuum standards, but research leading to the development of new low and medium range vacuum standards is carried out.

NBSIR 75-932
THE NATIONAL TEMPERATURE MEASUREMENT SYSTEM

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March 1975

EXECUTIVE SUMMARY

Temperature is a well-defined, basic scale quantity. It is perhaps the most commonly-measured of all the physical units (the possible exception being that of time). This very ubiquity, however, has a double effect. We desire (in principle) that we should have access to very accurate thermometry, but, on the other hand, we tend to take the measurements for granted, so that our practice of thermometry is often of poorer accuracy than we suspect.

The direct temperature measurement and control industry is a large one by any standards, including several dozen multi-million dollar firms. The amount of economic leverage which thermometry exercises is multiplied greatly, however, by the fact that good thermometry is essential to the commercial success of many industries, such as semiconductor, steel, chemicals and plastics manufacturing, medical testing and care, and precision instrument manufacture and use. Temperature is acquiring a new urgency in other areas as well, with the tremendous demand for new sources of energy; with the more stringent pollution and efficiency requirements under consideration for automobiles and aircraft; with the heavy new demands for safety and output being placed on nuclear power reactors; and with the desire to map and exploit the ocean's depths.

In briefest terms, NBS is meeting the heaviest of today's demands. The temperature scale is known and can be transmitted on demand with an accuracy which is satisfactory for most purposes in the range 20-1300 K. The calibration services offered by NBS for platinum resistance thermometers, for liquid-in-glass thermometers, and for thermocouples answer most of the direct needs for accuracy in that range.

Yet many human activities suffer a lack of adequate thermometry, even in the same 20-1300 K range. The particular reasons for this situation are numerous, but they come down to a few general problems:

1) Adequate thermometry exists, but it is not applied to the problem. The whole field of practical medicine suffers from this difficulty.
2) The type of measurement which is needed is not one for which a calibration rationale exists. Fast-response, hostile environment, and geometrically-constrained thermometry requirements exist in many fields of endeavor; many of these are noted in the full report.
3) The calibration procedure which exists is too expensive to justify, considering the economics of the activity. The homely drugstore thermometer is an example of this problem—a $10 calibration of a $1 thermometer is simply impractical.

Adding to these problems those which exist where the temperature scale is *not* adequate to today's needs gives one a fair picture of the opportunities which lie before NBS in thermometry today.

Again in brief terms, NBS thermometry programs lie in several general areas:

1) Generate an adequate scale below 20 K and above 1300 K.
2) Devise calibration and temperature standardization procedures which will solve people's problems, rather than simply transmitting the highest attainable accuracy.
3) Participate in the development of thermometry methods in areas where glaring weaknesses exist.

The NBS temperature measurement activities impinge on the U. S. temperature measurement system directly in a multitude of ways. The most obvious, of course, is through the calibration of precise temperature sensors. A second interaction is through NBS participation on voluntary standards committees; that is a quite important activity, because it serves both to communicate to others expertise and data originating at NBS and to alert the NBS staff to problem areas. A third major interaction with the temperature community arises through NBS staff participation in the development of measurement methods—in general, this interaction occurs directly with one or more technical thermometry groups in industrial or scientific laboratories. Many such instances are detailed in the report.

The National Measurement System study has been a valuable tool in our effort to focus our limited resources on the most pressing and susceptible problems. We intend to continue to use this approach to assess and, if necessary, to modify the NBS temperature program.

NBSIR 75-933
A STUDY OF THE NATIONAL HUMIDITY AND MOISTURE MEASUREMENT SYSTEM

Arnold Wexler
NBS Heat Division
March 1975

EXECUTIVE SUMMARY

Water in the form of vapor and liquid (moisture) is an ubiquitous substance that pervades our earth affecting almost every material, process, device, instrument and product. Life itself depends on its presence. It plays an important role in the scientific disciplines, in many branches of engineering, in medicine, meteorology, and agriculture, and in such diverse industrial fields as air conditioning, drying, refrigeration, storage, food processing, electronics and communications. Because of the innate interaction between water and its surroundings, and the pervasive effect water has, it is essential to be able to determine or adjust the amount present, that is, to be able to measure and control its quantity in a given environment or material.

Instruments which measure water content in the vapor phase are classified as hygrometers; those that measure water content in the liquid phase, that is, that measure moisture in liquids and solids, are classified as moisture meters. This study delineates the infrastructure of the humidity and moisture measurement system and the interrelationships that exist between the fundamental units, the standards, the calibration procedures, the instruments, and the users. It examines the impact that this measurement system has on economic, scientific, social and industrial aspects of our national life. Finally, it identifies and analyzes certain deficiencies and needs in the National Measurement System.

The primary responsibility of NBS is to provide the central basis for the National Measurement System, to coordinate that system nationally and with those of other nations, and to furnish the essential services leading to accurate and uniform measurements throughout the USA. The study shows that the NBS base for the humidity measurement system comprises five primary elements: (1) measurements research, (2) standards development, (3) development of special instruments for specific end uses, (4) prototype development and construction of new instruments to meet the needs for secondary standards, and (5) issuance of publications, such as monographs, to provide users with information on instruments, methods of measurement, sources of accuracy, NBS capabilities, etc. Coordination is achieved through the dissemination of information, data, techniques, methods, procedures, references and reprints to Government, industry, colleges, universities, institutes, industrial laboratories, foreign governments and foreign organizations. One important link in the coordination chain is the presentation of tutorial lectures before professional societies, workshops, seminars, clinics, and training courses. Direct services are offered through (1) calibration of plant and laboratory standards, (2) tests for compliance with government procurement specifications, (3) evaluation and testing of sensors for special government programs and (4) tests for the public when commercial, industrial, or university laboratories cannot meet required needs.

This study categorizes and classifies the instrumentation in current use in terms of principles of operation, commercial sources, and end uses. At least twenty-four distinct types of humidity instruments and controls are known to be made in the USA. These are available from more than 100 manufacturers.

Information gathered so far indicates that the annual business volume of the identifiable instrumentation industry for humidity and moisture measurement and control is of the order of 35 to 70 million dollars. This instrumentation impacts on a great diversity of disciplines, industries and technologies, creating a second order effect that is estimated to run into the billions.

In the process industries such parameters as temperature, flow, liquid level, pressure, chemical composition, density, viscosity, humidity and moisture are monitored and regulated. It is estimated that of the total number of such measurements, humidity constitutes 3.5 percent and moisture 0.7 percent. The economic loss resulting from measurement inaccuracies is substantial. For example, the uncertainties in the determination of moisture in grain, such as corn, can result in annual dollar losses from excess moisture or excess drying of $135 to 375 million.

The amount of water in a material is of vital commercial concern--in buying, selling, shipping, etc. It greatly affects the

properties of materials. The relative humidity of the environment and the moisture content of a given material must be controlled for many industrial processes and for the production of a great many products. Only through such control can such factors as product uniformity, quality, and process economy be achieved. Such control contributes to the conservation of fuel and energy in drying processes. In the testing of many materials for strength, performance, life, etc., humidity control plays a paramount role. For example, a review of American Society for Testing and Materials (ASTM) standards has identified at least 45 categories of materials that must be conditioned in cabinets or rooms prior to test and 84 categories of materials covered by procedures for the measurement of moisture content. Other organizations having standards, specifications or procedures involving humidity or moisture measurement and control include Air Conditioning and Refrigeration Institute (ARI), American National Standards Institute (ANSI), American Petroleum Institute (API), American Society for Agricultural Engineers (ASAE), American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE), American Society of Mechanical Engineers (ASME), Association of Official Analytical Chemists (AOAC), Cooling Tower Institute (CTI), U. S. Department of Agriculture (USDA), U. S. Department of Defense (DOD), Technical Associations of the Pulp and Paper Industry (TAPPI), Underwriters Laboratories (UL), International Organization for Standardization (ISO), International Electrotechnical Commission (IEC), U. S. Department of Commerce--National Oceanographic and Atmospheric Administration (NOAA), and the World Meteorological Organization (WMO).

This study has disclosed several shortcomings and deficiencies in the National Measurement System. As an example, there are no national standards for moisture measurements. Various technologies have established recommended practices or specifications through voluntary documentary organizations such as The American Society for Testing and Materials. In the agricultural field, the U. S. Department of Agriculture and the Association of Official Analytical Chemists have established reference methods for determining moisture in specific materials, yet none is directly traceable to NBS.

As a result of this study, and in response to requests from state weight and measures officials, NBS has initiated a program with the broad goal of providing the central basis within the USA of a consistent measurement system for moisture in materials and to provide essential moisture measurement services throughout the Nation.

NBSIR 75-934

THE NATIONAL MEASUREMENT SYSTEM FOR THERMODYNAMIC PROPERTIES OF FLUIDS

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August 1975

EXECUTIVE SUMMARY

This report describes the national measurement system for the generation of data on the thermodynamic properties of fluids, specifically the thermosphysical properties such as vapor pressure, heat capacity, and the equation of state. The institutional and human elements of the system consist of producers, evaluators, and users of such data.

Thermodynamics describes the transformation of energy and especially its interconversion as heat and work and its involvement in chemical prodesses. Fluids are ideal media for applied thermodynamic purposes, so that knowledge of their thermodynamic properties is of high importance. Thermodynamics is a subject of enormous generality whose utility in science and technology is is all-pervasive. It plays a central role in many disciplines of physics, chemistry, engineering, and the life sciences. Technologies impacted include the design of engines for producing work (e.g., steam turbines), processes for purification through phase separation (e.g., distillation and selective freezing), the design of chemical reaction systems (e.g., as used in petroleum cracking and in heating), and the design of means for obtaining very low temperatures (e.g., as used for preserving material, food and medicine, and for obtaining special low temperature properties like superconductivity). Industries impacted include chemicals, petroleum, natural gas, electric power generation, aircraft production, and transportation. Societal problems affected include the maintenance of air and water quality, the production, distribution and consumption of food and energy, the disposition of waste, the design and maintenance of health care facilities, and the efficient use of mineral and material resources. The pervasive influence of thermodynamics makes the assignment of resources to producing outputs for this measurement system very cost effective since a small investment can have broad economic and social impacts.

While economic impacts can be described, a detailed assignment of meaningful dollar values is difficult. Scientific and technological impacts of any particular data generation effort may be equally hard to document. Outputs of such efforts are typically freely available to all comers (e.g., in the technical journals) and there is no easy way to know who they are and how they may be using the outputs. The report contains a number of detailed examples of the economic role played by accurate outputs from this system. By implication, these describe the economic role of the NBS contributions to this measurement system since NBS outputs are generally of the highest accuracy.

The total amount of data demanded from this measurement system by its users is truly astronomical and cannot possibly be produced by measurement alone. Substances of interest are normally mixtures and often consist of several components, sometimes distributed over several phases. Data are usually needed for a wide range of compositions, with a range of temperatures and pressures needed for each composition. Because of this large data need, the development of theoretical models of varying degrees of empiricism plays an important role in the system. Such models can be used in a wide variety of applications, perhaps the most important of which are for the rapid estimation of the feasibility of industrial processes, for control of industrial processes during operation, and in the analysis of experimental measurement designs. Extrapolations are often made to conditions other than those for which data are available or to material systems for which no measured data exist. Such extrapolations must be based on accurate models, which, in turn, require in their development data of the highest accuracy on representative substances.

Because material and energy supplies have, until recently, been abundant and cheap, highest accuracy has not been a major concern in the design of most industrial systems which require the application of thermodynamics. However, because of current needs to conserve energy and material and to predict the environmental impact of plants before their construction, demands can now be expected for designs and analyses based on thermodynamic data of the highest accuracy.

Currently, the best attainable accuracies for the thermophysical properties under consideration lie in the range 0.01-0.5 percent. Because measurement of these properties is difficult and hard to automate, the accuracy attainable is generally much less than that needed. By implication, this defines a strong role for NBS in the development of improved national measurement capabilities.

Needs of the system are many and include the development of rapid automated measurement methods (especially for pressure and composition), the production of data on a wide selection of mixtures carefully chosen to provide insight into the role of molecular properties, the development of methods for describing the entire PVTX surface of fluid mixtures of various kinds, the development of accurate measurement techniques for transient equilibrium measurements and those under extreme environmental conditions, the development and application of new techniques (especially optical ones), the development of fluid theories for systems of non-spherical molecules, and the production of data and understanding regarding nucleation phenomena.

The basis for an NBS role in a measurement system whose outputs are so directly involved in technology and fundamental science is clearly stated in its organic act. The NBS has, since its inception, indeed been active in the generation of thermodynamic data, having produced benchmark data and publications, some of which still play central roles even after over half a century after publication. NBS outputs have provided the knowledge to support vast improvements in entire industries, such as agriculture (ammonia fertilizer), electric power generation (steam), plastics (ethylene), and steel (oxygen). The acquisition of data of sufficient quality to be called reference data is still so time consuming as to be rarely undertaken outside a laboratory like NBS, hence the especially strong NBS role at the highest level of data accuracy.

The NBS appears to be doing a good job of communicating with the user community. Some improvement is needed in developing communications with the portion of the user community at the ultimate use point. Much has already been done on this. Meetings between users and producers of data are being planned.

Satisfying the entire set of system needs will be difficult for the producer part of the system. A concerted effort will first be needed to overcome the negative effects of declines in recent years. These declines resulted from an emphasis on short range research (whereas the major problems of the system are long range), a lack of incentive among the mission-oriented government agencies for the support of research aimed at developing new experimental and theoretical techniques, a reduction of the number of students available at universities and the difficulty of predicting the future availability of students, and a reduction of funding for basic research over the past several years.

These needs contain much which properly fits the NBS mission. NBS resources are, however, insufficient to cover them even with rather extensive reprogramming, and selection is needed. The development of measurement techniques for rapid data taking, the taking of needed data, and the development of predictive theories of mixtures have been taken as programs for NBS concern in the near future, provided sufficient NBS resources are available.

NBS resources available for producing outputs in this measurement system are small and have other programmatic demands on them. Approximately 50 percent of the current financial support comes from outside sources. These resources, while supporting outputs into the measurement system, nevertheless do this from the point of view of the organizations supplying the funds. This reduces considerably the ability of the NBS to design programs according to the needs of the measurement system as a whole. With growing demands expected, NBS resources applied to this measurement system will need to be increased in the near future.

NBSIR 75-825
THE NATIONAL MEASUREMENT SYSTEM FOR CRYOGENICS

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August 1975

EXECUTIVE SUMMARY

The National Bureau of Standards is not responsible for only one unit of measurement, or even a set of measurements. Rather, the legislative mandate calls for NBS to provide a base for such a *system, coordinate* that *system,* and furnish essential *services.* Thus it is the responsibility of NBS to assure the proper functioning of the Nation's *system* of physical measurement, the National Measurement System. Accordingly, the present microstudy was conducted to examine and document the way in which the NBS Cryogenics Division is meeting its particular responsibility to assure the proper functioning of our system of cryogenic measurement.

The Cryogenics Division of NBS provides the measurement and data services that support a whole technology. Almost every category of measurement and data service is offered that NBS as a whole provides: not just an instrumentation system (including, for example, pressure, temperature, density, liquid level, flow rate, etc.), but also properties of fluids (both thermodynamic and transport properties); properties of solids (thermal, mechanical, and electrical); an interface with the users through systems integration, and advisory and consulting services; and our own dissemination network through the Cryogenic Data Center.

This study shows that there are three specific emerging technologies within this broad area of Cryogenics which need a complete and consistent system of measurements and data.

For instance, a comprehensive measurement system for *liquefied natural gas* needs to be developed, with special emphasis on quantity gaging in storage, flow-metering for both mass and heating value, and basic measurements of thermal and mechanical properties of structural materials.

Basic measurements and data are required to support the development of *hydrogen* as a fuel, to improve hydrogen liquefaction efficiency, to recover liquefaction energy, to document hydrogen-compatible materials of construction, to develop improved insulation materials, plus measurement tools and techniques for the eventual commercial exchange of liquid hydrogen.

Superconductivity connects cryogenic measurements and data to the electrical power industry, for power transmission, generation, and storage. Knowledge needed here includes heat transfer rates, behavior of helium refrigerant flow systems, and the degradation of the superconductors with time and stress. Other practical uses of superconductivity are becoming apparent, such as the application of Superconducting QUantum Interference Devices (SQUIDs) to problems ranging from mineral prospecting to magnetocardiography. Accordingly, the needs to support this technology encompass instruments and techniques for physical measurements plus a technical data base.

The technologies discussed above show the importance of cryogenics in commerce in the U.S. today, and also show its truly diverse applications. If there were a "General Cryogenics Corporation" like a General Motors, it would appear in the top 10% of the Fortune list of the 500 largest U.S. Industrial Corporations. But it is important to note that there is <u>not</u> a "Cryogenics Corporation", *per se.* Cryogenics is an infrastructure industry. Similarly, the national system of cryogenic measurements is an infrastructure of cryogenic technology itself. The crucial question of this report is, how well does the measurement and data structure support the technology as a whole?

This study shows that some parts of the cryogenic measurement system seem to be characterized by adequate services and quality assurance (cryogenic temperature measurements, for instance). It appears one should have less confidence in other parts of the system. Pressure measurements, for instance, which are probably the measurement most widely made in all of cryogenics, appear not nearly so well supported, especially pressure measurements in extreme environments. Attention by NBS to these issues is in order.

Especially apparent at this time is the need for a different kind of measurement, namely one that describes the *quality* or *availability* of the commodity. Specifically, we refer not so much to the flow measurement of liquefied natural gas, for example, as to the need to measure its potential heating value.

It appears that one component of the problem of cryogenic measurement is that the field is somewhat static. There has been no concerted national effort since the peak of the space program.

A second part of the problem arises from the way cryogenic measurements fit into the National Measurement System. As long as only a single agency or one sector of our economy (National Aeronautics and Space Administration, the aerospace industry) was using essentially all of the results of its own measurements, then that part of the National Measurement System was internally consistent and in harmony with itself. Now, however, cryogenics is becoming more commercialized and moving to the market place, and thus external consistency as well as internal consistency is required to make this part of the National Measurement System work.

The third part of the problem is perhaps a derivative of the first. Because the field is relatively static, a crucial question is not being asked: are there predictable technological developments that will either create a need for new cryogenic instruments, or possibly provide an altogether new measurement means?

Certain parts of the cryogenic measurement system at the national level seem to be disconnected, or working independently of one another at this time. For instance, our perception is that the U.S. Coast Guard has the necessary authority to regulate certain aspects of liquefied natural gas transportation by setting certain physical standards, measurement codes, and practices. They may do this without necessarily having recourse to the NBS. Other national authorities, especially in the area of public safety come to mind. Accordingly, it appears that this part of the measurement system is disjointed. There is no objective reason why it should remain so. It would be in accord with the NBS mission and tradition to pursue these issues and resolve them.

A goal of this study was to achieve both conceptual breadth and depth by examining our role in the national measurement system as a whole, and illustrating this role with a specific case study, the liquid nitrogen flowmetering program. This program was instigated by the needs of state weights and measures officials, the industry concerned, and the public for confidence in the custody transfer of liquid nitrogen. This effort used nearly every competence and capability that NBS has developed: measurement services (tests and calibrations of meters), property data (thermodynamic property data for cryogenic fluids), standard codes and practices (Handbook 44), dissemination services (Office of Weights and Measures, the National Conference of Weights and Measures), and both voluntary and regulatory standards activities (through the most relevant industry group concerned - the Compressed Gas Association, and by adoption in state codes).

The general conclusion of this study is that the cryogenic measurement system is doing its job adequately at reasonable cost. There is no widespread feeling of inadequacy, such as that which led to the creation of the National Bureau of Standards seventy-five years ago. On the other hand, there are both systematic and specific deficiencies that can and should be corrected. Further, there are several areas in which the cryogenic measurement system will be subjected to severe strains in the foreseeable future, unless appropriate responsive steps are taken soon.

Specific needs and responses, which are only summarized here, are documented within the body of the report.

NBSIR 75-935
THE NATIONAL MEASUREMENT SYSTEM FOR ELECTRICITY

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October 1975

EXECUTIVE SUMMARY

Electrical measurements are of critical importance due to the universal use of electricity as the primary means for the transmission and control of energy and data. The National Electrical Measurement System is that set of laboratories, organizations, documents, and people which make possible and are responsible for all electrical measurements made in the U.S. at all levels of accuracy. This document summarizes the results of a three-year study of that system.

The structure of the system may be conceived as having a number of components, each serving a particular sector of society and each having distinct characteristics reflecting differing requirements. Two major components exist: the industrial electronics component and the electric power industry component. There are a number of minor parts as well.

Electrical measurements in the system's industrial electronics component are used to insure quality and reliability of materials and manufactured products, to provide for interchangeability of components and parts, and to control manufacturing processes.

This component can also be further sub-divided into two general areas: the measurement-intensive industry segment and the general industry segment. Measurement-intensive industry and ite measurement system are characterized by high technology and the need for a very high degree of product reliability. Thus, included in this portion of the system are the instrumentation, aerospace, defense, communication, computer, and electronic component industries. Measurement accuracy within this segment is insured by a hierarchical laboratory system in each organization. Test equipment used for quality and process control is calibrated periodically using precision instruments which are in turn calibrated by comparison with primary standards in the corporate standards laboratory. These corporate primary standards are then periodically calibrated at the National Bureau of Standards or intercompared regularly with standards which have been so calibrated. This system, which in large organizations can have a complex hierarchy of laboratories, is primarily the result of the quality control requirements of DOD, GSA, and NASA procurement contracts and the requirements of regulatory agencies such as EPA and OSHA.

In the general industry segment of the system, quality control requirements are usually less stringent than in the high technology segment; accuracies are generally lower; and the manufacturing processes are less affected by absolute accuracy of measurements. Thus, organizations in this portion of the system are inclined to buy calibration and repair services from instrumentation manufacturers, large corporate laboratories in the aerospace industry, or companies specializing in calibration and repair work. As previously noted, each of these generally maintains a rigid, well-defined measurement support system.

There appears to be a number of problems and shortcomings in the industrial electronics component of the system. Among the most important are a lack of standards (written and artifact) for the support of dynamic, high-speed electrical measuring instruments and automated test systems; the non-availability in certain areas of procedures and test techniques of guaranteed reliability; a potential future shortage of competent measurement personnel; a failure on the part of some people in the system to perceive that calibration is not always a sufficient condition for assurance of measurement quality; and an inherent rigidity in the government contractural requirements which stifles innovative approaches to measurement problems.

The electric power industry segment of the National Electrical Measurement System can also be divided into two parts: operational and research for improved electric power transmission and distribution. Electrical measurements play an important role in the day-to-day operation of the nation's electric power systems. They are used to control the generation and transmission of

electricity, to provide a basis for equitable exchange (energy metering), and for testing machinery and equipment supplied to the power companies.

Measurement support for both of these areas is generally provided by the measurement laboratories of power companies and those of the electrical equipment manufacturers. In the energy metering area, many of the state and local public utility commissions which regulate the power companies require acceptance testing of watthour meters as well as retesting of older meters. NBS calibration of physical standards and electrical apparatus, both at NBS and in the power companies' and manufacturer's laboratories, insures the overall integrity of the system.

Most of the industry - both utilities and manufacturers - is adequately equipped to measure traditional quantities such as current and voltage at levels up to 15 kilovolts. Fewer companies, especially in the utility sector, have capabilities above 200 kilovolts. At extra high voltage (EHV) and ultra high voltage (UHV), the utility companies, with rare exceptions, have little measurement and calibration capability. Such capability, however, does exist with the manufacturers of large electrical equipment. With respect to non-traditional quantities, such as high transient voltages and currents, measurement capability is generally available only with the large equipment manufacturers.

The quality and consistency of electric power system-related measurements, including traceability to NBS-maintained standards, follow the above pattern of measurement capability. Whenever the calibrations are relatively simple and inexpensive, and if there is also regulatory incentive to do adequate work, the system is in excellent condition. A good example is watthour meter calibrations. But for higher voltage, and especially for non-conventional measurements where the calibrations are difficult to perform and reliable methods are not always readily available, the system has deficiencies. Included in this category are EHV and UHV steady state measurements, and transient measurements in general.

Electricity will become the predominant form of energy in use before the end of the century. Consequently, a large research and development effort funded by the Energy Research and Development Administration and the Electric Power Research Institute is being directed at ways to increase the transmission capability and efficiency of the country's electric power systems. New high voltage and electrical-related measurements are required as transmission technology advances. Examples of the new technologies include cryogenic transmission systems, UHV overhead lines, compressed-gas insulated substations, and high-voltage direct-current transmission. Each is a relatively measurement-intensive, emerging technology area. While some older types of measurement methodologies can be adapted for these new areas, generally they cannot and some significant deficiencies now exist including accelerated aging tests of electrical insulation, and traceability to national standards for impulse measurements.

Two important additional components of the National Electrical Measurement System are associated with the scientific community and consumer electronics. Measurements made in laboratories not under DOD or NASA contract are generally supported by local instrumentation shops. In contrast with the usual practice in the industrial electronics component, periodic recalibration is unusual - calibration is generally performed only before and after a crucial experiment, or as part of a special maintenance effort. Measurements in support of consumer electronics, such as TV, stereo systems, citizen band and amateur radio, auto electronics, and general electrical work are usually of low accuracy. Consequently, manufacturers' claims of test equipment accuracy are accepted until malfunction occurs. This portion of the system has few, if any, serious technical problems.

In summary, the Electricity Division of NBS provides the basis for that uniform system of electrical measurement in the U.S. which permits equity in trade, interchangeability of components, the transmission and distribution of electric power, a means of maintenance for electronic equipment, the ability to control the quality of production, and the general advance of science and technology. This is achieved by developing improved means for realizing, maintaining, and disseminating the basic electrical units; by calibrating electrical standards, instruments, and systems for industry, government, and the academic community; by developing new instrumentation and measurement methods; by obtaining basic data and determining fundamental constants related to the electrical units; by ensuring that electrical m asurements carried out in the U.S. are consistent with those made in other countries; and by providing advisory and consultative services.

THE NATIONAL ELECTROMAGNETICS MEASUREMENT SYSTEM

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July 1976

EXECUTIVE SUMMARY

Electromagnetic technology is the practical exploitation of electromagnetic waves, propagating either in transmission lines or freely through the atmosphere, and occupying a very wide spectrum of frequencies. It has grown up within the limitations set by nature.

In the range of frequencies below a few hundred MHz components are cheap, most antennas are not very directional, and the background is noisy. This part of the spectrum is very heavily used by telecommunication systems, both for business and for pleasure. High performance brings no significant advantages to these systems, so accurate measurements of the characteristics of components are rarely called for. The FCC keeps order among the various users of the spectrum by assigning frequencies, which are checked routinely, and power levels, which are rarely enforced. Many electronic systems, such as computers and servo control systems, are unintentional transmitters and receivers of electromagnetic radiation in this part of the spectrum. Interference is therefore a severe problem, that calls for repeatable measurements of complex, fluctuating quantities, to be used as the basis for the assignment of responsibility for its resolution.

An extreme case of electromagnetics interference occurs when fields are strong enough to injure people. This is a real danger with radio and TV transmitters and leaking microwave ovens. Exposure to hazardous fields is regulated by OSHA, supported by measurements of the field levels in question.

Another aspect of electromagnetic waves in this part of the spectrum that is not yet fully exploited is their ability to penetrate to useful distances in rock, soil, concrete, water, etc., to probe structures of these materials to supply information for civil engineering or mining. This will require extensions in the formulation of electromagnetic theory and the acquisition of a base of data on the properties of materials, which are the subjects of research that is in progress now.

At frequencies in the range from about 300 MHz to 30 GHz we find a higher preponderance of more sophisticated systems. Here wavelengths are short enough that highly directional antennas are quite common. The background noise is low enough to enable systems to operate with very weak signals. This range of frequency is used by most of the radar systems on which modern navigation depends, both for ships and for airplanes. Improved systems such as discrete address microwave beacons are under development for air navigation. Microwave systems are under development for landing in conditions of poor visibility. The armed services use radar for the automatic guidance of terrain-following aircraft and of weapons, as well as for searching for the enemy. On the highways, the police use radar for speed control.

In addition to radar, this region of the spectrum is used for telecommunications. Most long-distance telephone traffic is carried by microwave beams between repeater stations in direct line of sight with each other. Satellite communications are a rapidly growing business. The driving force in the expansion of the telecommunications industry is the trend towards having distant computers communicate directly with one another. In addition to demanding large channel capacity, computers and the associated digital technology encourage a trend towards digital communication, and separating different messages in time rather than frequency. This also has advantages for transmitting the voice, in the efficiency of use of channel capacity and the quality of the transmission. This is generating a new demand for time-domain measurements. The electromagnetic systems that use this part of the spectrum tend to be expensive, but to repay their expense with very high performance if they are carefully designed and maintained. For this they require the support of accurate measurements.

The region of the spectrum from 30 GHz to 300 GHz is presently regarded mainly as an overflow for users of the crowded channels at lower frequency. Components become much more expensive and less efficient in this region, and the atmosphere has strong absorption bands. The most significant commercial system, under development in several countries, is for telecommunication at 90 GHz through oversize circular waveguides.

There is not much commercial activity at frequencies between 300 GHz and 100 THz. There is much scientific activity in the development of lasers, and the world's most accurate spectroscopy is done in this region. Surely commercial or military exploitation will follow, especially of the CO_2 laser, which can already be made to be cheap, efficient, and powerful. There is some activity with military funding to develop it into a weapon, and the most significant measurements to be made are of its beam profile and energy output.

The near infrared and visible parts of the spectrum are used for all the activities that the possession of eyesight has suggested to us, in addition to some that had to await the development of instruments. These include the remote sensing of temperature by radiometry, and all the possible applications of visible lasers, such as alignment and measurement of linear displacement, micro-machining and surgery, holography, information processing (especially Fourier transformation), video disc recording, and automatic checking of groceries at the supermarket. Obviously, a very diverse collection of measurements must be made to support these activities, not the least important of which is the measurement of power and energy to regulate safety.

One newly developing optical technology that has much in common with the corresponding microwave techniques is telecommunication through optical fibers and the integrated electro-optical systems that will be used for transmitters and receivers. These will call for all the types of measurement that have been made on microwave systems, translated to a different region of the spectrum with different difficulties and conveniences.

In general, electromagnetic measurements do not attempt to attain the degree of accuracy that is possible for DC electrical measurements. Practical systems must be designed to tolerate variations of a few percent in circuit parameters due to instability of components and variations in operating conditions. Therefore measurements with uncertainty less than 0.1% are rarely called for.

Another striking feature of the electromagnetic scene is the high demand for measurements of dimensionless quantitites, such as attenuation, phase angle, reflection coefficient, and antenna gain. There are national standards and calibration services for many of these, but the trend is to replace them with self-calibration techniques.

Reference to the SI base units is tempered by the modest requirement for accuracy. The ohm can readily be independently realized in the form of a length of transmission line whose characteristic impedance can be calculated from its geometry. The amplitude of waves is determined by measuring power, voltage, current, electric or magnetic field. The essential step in all these measurements is the conversion of the quantity to be measured to an equivalent DC quantity. Reference of the latter to the basic SI units is a trivial step at the level of accuracy required.

The foreseeable future challenges to the National Electromagnetic Measurement System will come from: heavier use of the "underdeveloped" parts of the spectrum, such as millimeter waves, and the infrared and visible, for communication; wider use of multimode transmission lines; the quest for optimum use of time division multiplexing and the consequent need for the precise characterization of the time-domain response of devices, systems, and materials; and the new forms of interference that all this activity will generate.

NBSIR 75-937
THE NATIONAL MEASUREMENT SYSTEM FOR MEDICAL ULTRASONICS

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February 1976

EXECUTIVE SUMMARY

The medical applications of ultrasonics have increased at a rapid rate during the past five years. Ultrasonics is used for diagnostics, therapy (diathermy) and surgery. The most important of these is the diagnostic applications. Recent advancements in signal processing techniques and hardware have made possible the conversion of ultrasonic images to real-time optical images of good quality. Systems employing complex phased arrays of transducers are now in the laboratory stage and will find their way to the practitioner within the next two years. A large amount of activity is going on in these developments in university laboratories, manufacturers, and non-profit organizations. The size of the field of medical ultrasonics is estimated to be between $50M and $100M. These figures include doctor's fees, research and equipment production.

Reviews of the literature have uncovered a considerable concern with regard to the toxicity of ultrasonic waves on certain parts of the body. Since ultrasonics is widely used in fetal studies, a large amount of the concern was in this area. Certain consumer groups (e.g., Ralph Nader) have testified before congressional committees detailing their concern over this new medical tool.

Research into the toxic effects and damage thresholds of ultrasonic radiation are in progress at various research hospitals, universities, etc. However, it is expected to require several years before definitive, quantitative results are obtained. In the meantime, damage threshold measurements are hampered by a lack of physical standards. Measurement consistency between various researchers varies by an order of magnitude in some cases.

The National Measurement System as it applies to medical ultrasonics is fragmented, unco-ordinated and inadequate. Measurement capability for the more important parameters, power, intensity, and beam pattern, is mostly centered in development laboratories, certain manufacturers, and government laboratories. The Bureau of Radiological Health (BRH, DHEW/FDA) maintains measurement capability designed to aid in their role as the regulatory agency under provisions of the Radiation Health and Safety Act of 1968. The Electromagnetics Division of NBS began standards development three years ago and now offer a limited calibration service at 1, 2, 3 and 5 MHz for total beam power. Also offered is a measurement service for efficiency of high-Q quartz transducers in the band 0.5 to 10 MHz. Accuracies at NBS are 5% or better as compared to 10% to 15% in the field. A serious hindrance to more widespread standards dissemination is the lack of a suitable transfer standard device. It is believed that a low-cost, rugged and reliable device can be developed for use by both technical and non-technical (medical) personnel.

National laboratories in foreign countries, notably West Germany and Australia, have developed standards for important ultrasonic quantities and offer a more complete measurement service than does NBS at this time. At the PTB in West Germany, for example, the ultrasonics group consists of 15 people and they have been working in the field for more than 12 years.

As a result of announcement of NBS services (August, 1974), numerous inquiries have been received, calibrations have been performed, and negotiations are in progress for intercomparisons with two leading university laboratories. Intercomparisons with BRH have been carried out and the importance of this to that agency was quite significant in that they were able to proceed with the preparation of regulatory documents. These documents will prescribe that all ultrasonic medical equipment be metered for power output and that the accuracy of the metering be within certain limits. This is expected to create a demand for NBS measurement services from manufacturers who wish to insure that their equipment meets BRH requirements.

Close cooperation and exchange of information is maintained between NBS and BRH. For example, information gained by BRH in their field surveys and contacts with manufacturers is passed on to NBS. The BRH program in ultrasonics standards is aimed at development of working standards for use in their regulatory role. They look to NBS for development and maintenance of basic standards.

For the future, the Electromagnetics Division has under development a precision scanning system (computer controlled) to yield accurate measurements of field and beam patterns of ultrasonic transducers and arrays. This system is expected to become a major factor in solving measurement problems which now exist. A new calorimeter which is to serve as a basic standard for power measurement, is nearing completion. Thus, the potential impact of NBS on the important field of medical ultrasonics appears to be substantial.

NBSIR 75-937
THE NATIONAL MEASUREMENT SYSTEM FOR ACOUSTICS

David S. Pallett
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August 1975

EXECUTIVE SUMMARY

Acoustics, the branch of science dealing with sound, has become a field which plays an important element in many aspects of our contemporary technological society. Acoustical measurements are performed in order to quantitatively characterize noise levels, to specify noise emissions, to specify the acoustical properties of architectural materials, and to quantify and interpret human response to sound, to name but a few examples. This report describes acoustical measurement processes which are motivated by societal concern over noise and which are continuations or extensions of traditional acoustical measurements.

Ultrasonic non-destructive evaluation has evolved as an important relatively new application of acoustical technology in which acoustical measurements are used to identify and characterize flaws. These measurements are performed in order to meet the increasingly severe requirements for mechanical integrity and reliability as well as pressures for material conservation and increased productivity. The nature and importance of these measurements are briefly described.

Although the report describes a diverse range of acoustical measurement tools and methods, there remain numerous acoustical measurements not covered in this report. These deliberate exclusions include such important fields as physiological acoustics, physical acoustics, and underwater acoustics. The deliberate exclusions of these topics was necessary in order to limit the scope of the report and to direct attention to areas of acoustics in which the necessity of obtaining increased objective quantitative knowledge has recently become apparent.

The principal user groups for noise measurements include various departments, agencies, or laboratories of Federal and State governments; manufacturers of measurement instrumentation, products for which noise emissions are of immediate or potential concern, or architectural materials; acoustical consultants, architects, and urban planners; and university faculty and staff members affiliated with research laboratories or speech and hearing clinics. Users of ultrasonic non-destructive evaluation equipment include the aerospace, power generating, construction, metals production, auto manufacturing, metals fabrication, and railroad industries.

There are numerous identifiable social, technological, economic impacts for these measurements. Measurement of noise is now an important element in the protection of society's hearing. Conduct of some ten to twenty million annual audiometric examinations will soon demonstrate an increased level of awareness of noise and of the importance of hearing conservation in our society. Acoustical measurement processes are explicitly involved in noise control and hearing conservation. Economic impact is more difficult to assess quantitatively, and a well-defined picture of the economic impact of acoustical measurements is not yet available.

The role of the National Bureau of Standard's acoustics activities within the infrastructure of the National Measurement System is based primarily upon interactive processes which constitute the inputs and outputs for these activities. The substance of the interactive process consists of such elements as provision of and interchange of test and calibration data or technical reports, or the development of calibration and test procedures and measurement methodologies. Participants in this interactive process include standards organizations, professional societies and universities, representatives of foreign laboratories, and various industrial representatives (including trade associations as well as individual manufacturers). The principal industries involved include those whose manufacturing processes are inherently noisy, and those whose products are required for noise abatement and control.

Because of the increased legislative attention given to noise and its control, and of the consequent attention to the required measurement methodologies, the adequacy of these methodologies is now the subject of intensive study, both within NBS and within other Federal, State and local agencies.

The study indicates that there is a continuing demand for improved accuracy and precision in both the development and calibration of acoustical measurement instrumentation and in the evolution of improved measurement methodologies. Provision of

services such as these has traditionally been a strength of the NBS program in acoustics. The study also illustrates that a significant increase in the number and scope of legislative actions directed toward noise control has taken place. It is likely that this increase will continue, particularly as state and local governments become active participants. Inconsistencies in the relevant required measurements are apt to introduce ambiguities into the legislative actions, and the imprecisions inherent in these measurements may introduce inequities in trade as well as inhibit expansion of the technology. A need, therefore, is shown for acoustical research directed toward: the basic physical phenomena; the study and evolution of improved measurement facilities and instruments (tools); and the improvement of the required measurement methodologies (the use of the tools).

Continued study of the National Measurement System for Acoustics will facilitate improved communication between the various participants to enable adaptations of the system to meet changing needs.

NBSIR 75-939

THE NATIONAL MEASUREMENT SYSTEM FOR RADIOMETRY AND PHOTOMETRY

Henry J. Kostkowski
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April 1975

EXECUTIVE SUMMARY

This National Measurement System Study is on the measurement of light. More specifically it is concerned with the measurement of the energy or power in ultraviolet, visible and infrared radiation.

The study was undertaken to determine the importance of such measurements in the U.S., the accuracy and ease with which they could be made, the adequacy of this capability, and finally, the nature of the program NBS should pursue in this measurement area.

In the last ten years, the economic and social impact of radiometric and photometric measurements has increased significantly. Such measurements are required in the manufacture of cameras, color TV and copying machines. Ultraviolet radiation is being used extensively for the polymerization of industrial coatings. An attempt is being made to use radiometry in measuring atmospheric temperatures for the purpose of forecasting weather. New solid-state lamps (LEDs) are used in a variety of visual displays. Phototherapy is used almost exclusively in the treatment of some diseases (e.g. jaundice in the newborn). Regulatory agencies are concerned with the hazardous effects of UV on the eyes and skin (skin cancer), particularly in industrial environments. Dentists are now using a commercially available "UV gun" for curing various new dental materials. Applications in the lamp industry are increasing because of our energy problems. Twenty-five percent of the U.S. electrical power is used for lighting, and thus, developing lamps that will produce the same light for less electrical power has a high priority. Developing the utilization of solar energy will require better measurements than are now available. All of these uses and applications of light require radiometry or photometry. Many of them will require a state-of-the-art accuracy of 1% in order to achieve their objectives.

Unfortunately, the current radiometric and photometric measurement system is inadequate for the many uses and applications described. Radiometric measurements are among the most difficult measurements to make. The radiant power varies with position, direction, wavelength, polarization and time, and the responsivity of most radiometers also varies with these and other parameters, making such measurements a difficult, multi-dimensional problem. In addition, most of the people wanting to use radiometry have not been trained in the field. There are relatively few experts available. As a result of these two factors, measurement accuracy is poor and large differences in measurement are widespread. Much time and money is spent trying to resolve these differences, particularly when mass produced products require components from various companies and these components must meet radiometric or photometric specifications.

The cost of inadequate radiometry and photometry is very high. The electro-optical industry alone has annual sales approaching 15 billion dollars per year. A leading instrument manufacturer estimates that about $200 million is spent each year in calibrating radiometric systems or resolving discrepancies in radiometric measurements. If better radiometry can improve long-term weather forecasting as predicted, the economic impact would be tremendous. It is virtually impossible to estimate the cost of inadequate radiometry relative to medical and safety applications, but public health and safety are certainly given a high priority in this country.

Adequate radiometry today means making 1% measurements commonplace. This will require greater expertise in the system and more accurate, easy-to-use, and less expensive standards and techniques.

NBS has addressed itself to solving these problems. It helped organize the Council for Optical Radiation Measurement (CORM), a group largely representing industry and providing detailed information and a consensus of the needs in the system. It has worked with the Illuminating Engineering Society (IES), the Commission Internationale de L'Éclairage (CIE), and the Infrared Information Symposia (IRIS). NBS is developing more accurate, easy-to-use, less expensive standards and techniques and is beginning to monitor the capability of the system by interlaboratory comparisons. It has created specialized publications to insure that all this information is efficiently disseminated. Finally, NBS is also starting to produce a Self-Study Manual for Optical Radiation Measurements. This is expected to significantly upgrade the level of expertise in the U.S. in this area.

In summary, this study has shown that radiometry and photometry are having a significant economic and social impact in the U.S. today and this impact is expected to increase. The capability of this portion of the measurement system is inadequate for today's needs. One percent measurement is frequently needed; 10-50 percent is commonplace. The reason is that radiometric and photometric measurements are very difficult to make, and there is too little expertise to make these difficult measurements. NBS' program is designed to improve the situation by (1) making the measurements easier through simpler, inexpensive standards and techniques and (2) increasing the expertise through a Self-Study Manual on the subject.

NBSIR 75-940
THE NATIONAL MEASUREMENT SYSTEM FOR SPECTROPHOTOMETRY

William H. Venable, Jr.
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April 1975

EXECUTIVE SUMMARY

This microstudy covers the field of spectrophotometry and the work in this field being conducted in the Optical Radiation Section at NBS. In general, spectrophotometry provides an answer to such questions as how much light is reflected by an object or transmitted through it. ("Light" is used here in a very general sense which includes the light we see and other electromagnetic radiation in the adjacent portions of the spectrum which behaves in a manner similar to light.) The technological significance of spectrophotometric measurements lies in its use as a tool for determining something about the object. Combined with a knowledge of the way the human eye functions, spectrophotometry can be used to predict and control the way an object will appear. Thus spectrophotometry can become the "eyes" for the automated production and quality control in the manufacture of objects and materials in which appearance is important. Taken with knowledge of the optical properties of chemicals, spectrophotometric data forms a basis for quantitative chemical analysis in a huge variety of fields from clinical testing to manufacturing. There are countless other applications in such areas as photography, remote sensing, warning devices for safety, and nondestructive inspection of agricultural products.

As the foregoing indicates, the user community is huge. The processes in which spectrophotometric measurements are or could be significant are estimated to account for about one-fourth of the gross national product. It should be pointed out, that in most cases, the spectrophotometric measurement is only a small part of the total operation for a given user. As a result, the spectrophotometric measurement community for the most part is made up of a huge number of widely diverse individuals who use spectrophotometry as a tool and who do not have a strong knowledge of the field. They rely on the instructions which come with their instruments and on standard test procedures. This large, highly diverse community is the productive level of the spectrophotometric community.

At the next level above the user community lies practically all of the rest of this measurement system. The instrument manufacturers, the military, government, and commercial measurement laboratories, and the many committees which develop and publish the standard measurement techniques interact directly or nearly directly with the user community. The standards and services supplied by this second level are adequate for some applications, but if the full value of spectrophotometry is to be realized, the error in these measurements must be reduced by a factor of ten. With a reduction of error by this magnitude, one would just pass a very practical set of limits in the need for accuracy. These limits result from limits in the ability of the human eye to distinguish differences in appearance, limits in the ability or need to control production processes and limits in the precision with which samples can be prepared for analysis. The measurements must reach these limits in order to provide the basis for an orderly market place in which measurement errors have small economic or other practical consequences, and in order to allow full utilization of spectrophotometric analysis. Since there must be allowances for lag in feedback loops, these limits must be slightly exceeded in order to fully utilize spectrophotometric sensors in automated control of production.

In order to bring about such an improvement in the measurement system, a strong capability for highly accurate measurement must be built up. The instrumentation and labor required for this effort would be too much for any one of the instrument manufacturers of commercial laboratories to handle, much less for any individual user. To be economical, this capability should be in a central laboratory, and, in the interest of fairness, this laboratory should be on "neutral ground". Quite obviously, NBS is the laboratory for such universal standardization of these measurements to take place. From the mid 1950's until very recently, the spectrophotometry program at NBS was small and geared principally to measurements as a service to the rest of NBS and to other government agencies. However, during the past two years, the spectrophotometry program at NBS has been revised and our measurement capability is being built up to the

point where we can supply the leadership required for increasing the accuracy and extending the range of spectrophotometric measurements.

Through our study, we have clearly recognized the magnitude of the user community and the potential advantages which can come from an order of magnitude improvement in the measurements. We have gained an insight into what needs to be done by NBS in this respect and have initiated a program through which we can do our part. The new NBS capability should be fully developed during the next five years, at which time the full impact of our efforts will begin to be felt. Although we will maintain contact with individual users of the measurements in order to obtain a measure of the effectiveness of our program, our main point of contact will be with instrument manufacturers and secondary standards laboratories. Through measurement assurance programs and other assistance to these groups, we feel we can amplify our efforts most effectively to bring about the needed improvements in the measurement system. We will also be providing several very general standards through the Office of Standard Reference Materials.

The potential benefits which can be obtained from improving spectrophotometric measurements is estimated to be as great as two billion dollars annually, principally in increased productivity through automation. It is our intent to provide leadership which will enable to the scientific, technical, and industrial community to obtain those benefits as readily as possible.

NBSIR 75-941
THE NATIONAL MEASUREMENT SYSTEM FOR FAR ULTRAVIOLET RADIOMETRY

William R. Ott
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August 1975

EXECUTIVE SUMMARY

Radiometry is the quantitative measurement of radiant power. By restricting the region of interest to the far ultraviolet, the wavelength region from about 10 nm to 300 nm is specified. The corresponding photon energy range extends from 125 eV to 4 eV, very large compared for example with the visible range which extends only from 3 eV to about 1.8 eV. Because of this, a wide variety of phenomena and radiometric applications can be found throughout the far ultraviolet. This report is a description of the evolving National Measurement System in the field of Far Ultraviolet Radiometry; at the same time a critical evaluation of the NBS role in the System is made in order that we might optimize our efforts toward serving the System and thus promote progress toward the national goals of our government.

The technological importance of the far ultraviolet spectral region stems essentially from: (a) the increasing use of high temperature devices such as the fusion plasmas being produced in the search for new energy sources; (b) the industrial potential of far ultraviolet and x-ray lasers; (c) the high energy content of short wavelength radiation with the consequent ability to drive and control chemical reactions; and (d) the very low diffraction limit of short wavelength radiation. The problem areas where ultraviolet radiation measurements are important include both national research and development programs and major industrial applications in the following fields:

(1) Industrial Photochemistry
(2) Bacteriological Control
(3) Environmental Studies
(4) Medical Therapy
(5) Fusion Research
(6) Space Science
(7) Ultraviolet and X-Ray Lasers
(8) Plasma Chemistry
(9) Photobiology

In order to evaluate whether or not an ultraviolet radiation measurement capability is in the national interest and affects our well being and the common good, both the social and economic significance of those activities which depend upon such a capability are discussed. Examples of areas of impact where the ultraviolet measurement system enjoys considerable social and economic leverage are national health and safety and solar simulation.

Numerous studies which are cited in this microstudy indicate that ultraviolet radiation can be dangerous and can cause such things as incapacitating burns (sunlamps and arc welders are the biggest culprits), premature wrinkling, and skin cancer. In view of the increasing use of ultraviolet lamps in our society for illumination, advertising, bacteriological control, medical treatments and industrial polymerization applications, and in view of our recent concern with the disastrous consequences which would result from even a small increase in solar ultraviolet transmission through out atmosphere, a measurement capability is absolutely necessary. It is used not only to monitor the light environment and thus guarantee radiation safety but also to enable definitive experiments which will accurately specify the safety limits themselves. If the social benefit is obvious, the economic leverage is no less so. Our work force is weakened considerably not only by work-related radiation accidents involving arc welders, high intensity sterilization lamps, etc., but also by the common weekend-in-the-garden sunburn. Outdoor workers are especially affected and experience in addition a significantly high incidence of skin cancer. The statistics are available and one can easily estimate the economic impact of thousands of careers terminated in this way.

Accelerated weathering machines and solar simulators are used by the paint, dye, plastics, and building material industries as well as for space-related applications, for example, in determining the lifetime of solar cell arrays. Correlations up to now have not always been significant partly because the irradiance is specified by time exposed and not in terms of intensity and spectral distribution. Because of the uncertainties in the

lamp characteristics, not only are large amounts of money and effort wasted annually in the collection of misinformation and in some cases by the production and distribution of inferior products, but also the industries are discouraged from increasing their efforts toward developing superior weather-resistant products. Ultraviolet calibrations of these machines for wavelengths as low as 121.6 nm are required if accuracy, consistency, and cost effectiveness are to be achieved in testing. Manufacturers of the simulators are equally concerned with improved diagnostic methods since their world market could be threatened by the imposition of radiometric specifications on the machines by international standardizing bodies.

The NBS program on far ultraviolet radiometric calibrations is carried out in the Plasma Spectroscopy Section (232.07) and in the Far UV Physics Section (232.03). It consists of several complementary components and makes use of absolute detectors as well as standard radiation sources. The primary consumers of our vacuum ultraviolet services have been the space scientists who need absolute detectors and sources to determine the response of spectrometric optical systems. At present these users dominate by about 10:1 over the combined number of all other consumers. This statistic is due mainly to the chronology of how the National Measurement System has evolved: research and scientific explorations (NASA in the 60's) force the development of advanced technology which, in turn, stimulates and makes possible new applications of that technology. There is substantial evidence that we are entering this latter productive and potentially explosive stage. Nevertheless, it is shown in this report that there is little systematic interaction between the standards community and the users groups. Aware of this evolution and the changing priorities, NBS cannot only be open and receptive as it has always been, but must actively develop new contacts. It is recommended that NBS initiate more mini-workshops similar to the successful meetings involving several regulatory agencies, which we organized during 1972-1974. Photochemical and biomedical applications should be the first areas where NBS should generate such a new initiative.

There are several technical recommendations in this report which are the result of some preliminary contacts of the type just discussed.

(1) NBS, although boasting two complementary programs toward the development of primary, far ultraviolet radiometric source standards, currently supports no efforts to develop reliable transfer standards. This situation must be rectified in view of requirements for field uncertainties of about 1 percent between 200 nm and 300 nm, 5 percent between 90 nm and 200 nm, and 10 percent below 90 nm.

(2) We must plan to develop ultraviolet source standards of spectral irradiance, the unit of principal interest to the users. Unless this is done, we must leave it up to the individual users to generate their own irradiance standards by way of our spectral radiance standards. Not only is this an expensive and counter-productive way to go, but also it makes for a very uncertain traceability to NBS.

(3) NBS standard detectors, although fairly well developed, should be modified and improved so that they are usable by several high priority users who have applications requiring pulsed operation and/or high intensities.

(4) Internal consistency among the various NBS radiometric standards must be systematically checked. This includes such independent standards as photodiode detectors, synchrotron radiation, hydrogen arc radiation, electrically calibrated radiometers, and tungsten lamps.

NBSIR 75-942
THE NATIONAL MEASUREMENT SYSTEM FOR OPTICS

Dennis A. Swyt
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August 1975

EXECUTIVE SUMMARY

Measurements in imaging optics are fundamental to manufacture of products ranging from spectacles, microscopes, photographic goods and microfilmed documents to aircraft, nuclear reactors and oil pipelines; measurement quantities of interest are "diffuse visual density" which characterizes the darkness of photographic, radiographic and ink-on-paper images; and numerous measures of optical system performance (refractive power, resolution, optical transfer functions, etc.). Diffuse visual density is defined by ANSI documentary standards; many voluntary standards and federal specifications relate to its application.

These measurement are most intimately related to the photographic and optical industries. In figures characteristic of the early 1970's, their outputs included $1.3 billion worth of sensitized photographic goods, $4 billion in photographic products and $485 million in lenses and optical instruments. $5 million of densitometers and $35 million in non-opthalmic test equipment provided some of the means of measurement.

Some of the measurements are performed by:

*18,000 eye examiners and 20,000 dispensers of lenses supplying 100 million wearers of corrective lenses with opthalmic lenses costing $190 million in a $2 billion system of eye care.

*10,000 medical radiologists, supported by 90,000 technicians, examining 325 million x-rays of 110 million patients at a cost of $4 billion.

*15,000 industrial radiographers performing 45-90 million measurements in over 6300 plants at a cost of $350 million. Typical data for products affected by these measurements are $7.6 billion in aircraft, $4.6 billion in missiles and space hardware, $64 billion in nuclear reactors contracted for in the period 1965-73, and $600 million of pipelines constructed annually.

NBS provides diffuse visual density standards, microcopy resolution charts and an optical system and lens evaluation service. The density standards are used by, among others, the eleven companies which accounted for virtually 100% of photo film sales and 80% of equipment sales in 1970; the standards are required by AEC, NASA, DOD, FAA, and DOT specifications. The NBS Microcopy Resolution Chart is a voluntary standard for the $450 million microfilm industry and a mandatory standard for use in DOD microfilming operations; the NBS chart is on the verge of formal acceptance as an international standard. The lens testing services have primarily benefited federal agencies.

In eighteen month periods in which outputs of NBS were evaluated, a program which in 1973 consisted of 3 1/2 man-years of effort with a $319,000 budget (of which $118,000 was from other federal agencies) provided 15,000 microcopy charts, 200 density standards, 10 interferometers for an AEC prime contractor, a handful of lens tests, a number of special studies for federal agencies, a significant amount of testing and consultation on optical systems for security-classified federal agencies, as well as major publications on the theory and operation of advanced optical systems.

The primary effect of this study has been to reveal the nature of the users of NBS services and the degree of their dependency on the standards NBS supplies. Incremental analysis, the tracing of the economic effect of NBS services through causal chains to final products and services, has not proven feasible. Isolated examples of the cost benefit to users of their own measurements are given; e.g., the cost of a "traceable-to-NBS" radiograph may be $10: the part under inspection may be a flange for a nuclear reactor; economic loss to the reactor owner in down-time and repair work due to a flange failure: possibly $250,000.

Recommendations regarding NBS programs are to upgrade density measurement capabilities, to maintain without further expansionary investment the lens testing services, and to channel image analysis measurements toward optics-related measurement problems. Discontinuation of NBS services in this field, it is thought, would result in the provision of the same services by one or more other federal agencies. Continuation of the study of the measurement system might involve assessments of the desireability of NBS reference standards of reflection density and of the interest of optical manufacturers in a round-robin approach to measurement assurance in lens testing.

Documentary data and informed opinion for this study have been acquired by means of a survey questionnaire to 150 users of calibration services; canvassing letters to 30 instrument manufacturers, 25 trade and industrial associations, and 50 optical companies; personal interviews with 30 individuals at organizations throughout the country; innumerable telephone contacts; as well as direct use of documentary and library source materials.

NBSIR 75-944
THE NATIONAL MEASUREMENT SYSTEM FOR THE PHYSICAL PROPERTIES OF ATOMS AND MOLECULES

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August 1975

EXECUTIVE SUMMARY

The national activity in the measurement, compilation, evaluation, and dissemination of atomic and molecular data is represented here as a component of the national measurement system. The significance and validity of this representation rests largely on the role of the National Bureau of Standards in the development of measurement techniques, the encouragement of standards of measurement performance and in efforts to generate an adequate and well-documented data base effectively constructed to meet the needs of the user community.

The level of national activity in this field is estimated to be in the range of 20-25 million dollars annually, and the NBS programs in atomic and molecular measurements and in data evaluation and dissemination are approximately 3 million dollars of the total. The output of this activity has a direct impact upon applied research and development projects currently funded at a level well in excess of a third of a billion dollars annually. The largest of these are ERDA-supported programs aimed at energy generation and conversion (conventional controlled thermonuclear research, laser fusion, laser isotope separation, coal-burning magnetohydrodynamic generators, etc.). There are large potential benefits for a broad range of industrial research and development activities. Atomic and molecular measurements are also extremely important to basic research in astrophysics, atmospheric physics, plasma physics and aerodynamics.

Examples of recent and current contributions with large impact range from data on specific single processes which play a determining role in some development problems, such as the control of ion propulsion engines for NASA, to entire data sets with which the behavior of a laser plasma or an MHD generator may be programmed and studied with electronic computers. The maturing of this kind of computational capability is of the greatest significance for the advancement of the technology of plasma devices. This significance is well recognized by the atomic and molecular community which sees it as the vehicle for meaningful contributions toward solution of urgent economic and social problems. It is increasingly recognized within ERDA energy source development programs as an essential tool for orderly progress in their projects. It is generally less widely recognized in the industrial development community.

Certain atomic and molecular properties are used at the limits of achievable accuracy as the basis of the accepted standards for length, time and frequency. An atomic standard for mass is foreseen. Precision measurement techniques developed by workers in the field of atomic and molecular physics have been incorporated in the development of standards for measurements of other quantities, for example, gas pressure and radiant flux.

It is recommended that the National Bureau of Standards undertake activities which involve direct participation and interaction with the major governmental energy development projects, that it use this experience to guide development of new measurement methodology in atomic and molecular physics, and that it undertake to ensure the reliability and adequacy of the data base needed for these projects. Furthermore, it is recommended that the NBS expand its contacts with private industry, develop increased awareness of the methodology for applying atomic and molecular data to technological development, and provide such advice and guidance as will assure the effective utilization of this sector of the measurement system for the benefit of the economy.

NBSIR 75-945

THE NATIONAL MEASUREMENT SYSTEM FOR SURFACE PROPERTIES

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May 1975

EXECUTIVE SUMMARY

There is a large number of solid-surface properties that can be measured and these have been arbitrarily divided into two classes. First, there are the properties which can be used to characterize a surface: surface composition (as a function of position), surface atomic structure, surface electronic structure, the nature and distribution of surface defects, surface topography, and the nature and area of exposed facets. Second, there are derived properties of the surface characteristics as just defined and measures of the processes that occur on surfaces: electrical properties, optical properties, adhesion, bonding, catalytic activity, plating, durability, corrosion, decoration, grain-boundary segregation, lubrication, and reactivity. This report discusses directly only those measurements that are used for surface characterization with particular emphasis being given to the most common measurement, the measurement of surface composition, and lesser emphasis to the measurement of surface atomic structure and surface electronic structure. Measurement of surface topography is discussed in a separate report of this series by R. D. Young.

Throughout the report, the term "surface" is defined as the "outermost" layer of atoms of a solid. Thus, consideration is given primarily to those properties (and measurement methods) which are specific to the surface as defined. Some consideration is given also to the measurement of composition as a function of depth from a surface and at solid-solid interfaces.

A dramatic feature of this part of the National Measurement System is the rapid growth of surface science and surface technology and the substantial accomplishments that have been made in the past ten years. Surface science and surface technology are widely regarded as "frontier" areas in which major scientific breakthroughs and major improvements in materials and processes will occur.

Most of the measurement methods now in use for surface characterization have become commercially available within the past ten years. At this time there is a complete lack of standards, standard procedures, and standard materials to support surface-characterization measurements. In short, there is no established measurement system for the measurement of surface properties.

Most measurements of surface composition are now performed by Auger-electron spectroscopy and, to a lesser extent, by x-ray photoelectron spectroscopy, ion-scattering spectroscopy and secondary-ion mass spectroscopy. The sales of these instruments have been estimated to be about $10M per year with a current growth rate of 20 to 30% per year. About 60% of these instruments are in use in industrial laboratories, 20% in Federal Government laboratories, and 20% in university laboratories.

The surface-characterization measurements made in university and some other laboratories are frequently made to develop a fundamental understanding of the properties of relatively ideal (i.e., single-crystal) surfaces and of processes that occur on them. Surface-characterization measurements made in government laboratories support a variety of agency missions, ranging from national defense, space, energy, to the environment.

Measurements of surface composition are routinely made to solve an extremely wide range of industrial problems (of which examples are given). Most of these measurements are made in the semiconductor, chemical, petroleum, and metallurgical industries for applications ranging from process and device development, process control, process evaluation to failure analysis. The economic benefits were difficult to estimate but are believed to be substantially greater than the corresponding costs.

Continued growth in surface science and surface technology (and in the required surface-measurement capability) is predicted for the foreseeable future (the next five years). Present national goals for solution of the energy crisis, provision of an adequate defense capability, control of environmental pollution, increase of industrial productivity, and the development of advanced materials for improved individual health and safety and for the automobile and aircraft industries will require use of surface technology and improved surface-characterization measurements. Other factors which will stimulate growth in surface-measurement capability are projected developments in surface science, development of improved

instrumentation, development of quantitative methods for surface characterization, legal needs, and anticipated growth in the applications of surface analysis.

Present surface-characterization measurements make use of reference data generated by instrument manufacturers, universities, government and industrial laboratories, and by NBS. Many important measurement needs have been identified, the most important (for surface technology) being to provide data and procedures to quantify measurements of surface composition. It is anticipated that the development of standards, standard procedures, reference data, and standard materials will be coordinated through the recently formed ASTM Subcommittee E2.02 on Surface Analysis.

Other measurement needs in surface science and surface technology have been identified. Many surface properties and processes depend on the surface composition, atomic structure, and particularly the surface electronic structure. It is anticipated that future developments in surface science will lead to a more detailed understanding of the mechanisms of catalysis, corrosion, adhesion, lubrication, and wear so that new materials with improved properties can be designed. Advances of this type depend on the development and application of new measurement methods to characterize disordered surfaces, highly dispersed catalysts, transient species on surfaces, the kinetics of reacting species, and the properties of such surfaces in their working environments.

NBS programs in surface physics have had considerable impact on the development of surface science through the development of new instruments and measurement methods, the observation of new surface properties, the development of new theories and concepts, the provision of reference data, and the publication of data compilations and critical reviews. NBS data is also being used in surface technology. Additional NBS effort is required, however, to promote surface technology.

Twelve recommendations are given for NBS action to improve and extend the measurement services required for the support of surface science and surface technology. Meaningful action by NBS and other interested groups should enable the establishment of a satisfactory National Measurement System for the Measurement of Surface Properties in the future.

NBSIR 75-946
THE NATIONAL MEASUREMENT SYSTEM FOR IONIZING RADIATION

Randall S. Caswell
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March 1975

EXECUTIVE SUMMARY

The structure of the National Measurement System for Ionizing Radiation has been investigated for eight prime classes of radiation users: medical, nuclear power, industrial radiation processing, defense, environmental, science, chemical analysis, and miscellaneous radiation applications, plus two "overlay" categories, regulatory control of radiation and personnel monitoring. Needed major actions on the part of NBS were identified for nuclear power and its related environmental and safety impacts, medical applications of radiation, assistance to regulatory control of radiation and measurement assurance for personnel monitoring..

The regulatory control of radiation is divided among ERDA, the Nuclear Regulatory Commission, the EPA, the Bureau of Radiological Health, the Occupational Safety and Health Administration, the National Institute of Occupational Safety and Health, and the Department of Transportation. Forty-six states and Puerto Rico have passed radiation control legislation. Radiation regulation is normally administered by state health departments which vary widely in support, staff, and technical competence. They work together through the Conference of Radiation Control Program Directors. Needs defined are: (1) all regulators of radiation need to be on the same measurement scale; and (2) the great majority of state health departments would be benefited by a program of technical assistance in radiation and measurement. NBS has (1) instituted a program of measurement assurance testing to establish traceability with lead laboratories of ERDA, EPA, and other regulatory agencies, and (2) proposed a National Radiation Measurement Calibration System for the benefit of the states, regional calibration laboratories, and regulatory agencies.

About 800,000 persons considered radiation workers wear personnel monitors. Most such monitoring is supplied by fewer than 20 commercial suppliers, although government laboratories and the military services largely provide their own service. Two needs are apparent: (1) a high-quality measurement assurance testing laboratory to test monitoring services, and (2) monoenergetic neutron calibration fields to test and develop neutron personnel monitors. NBS actions in response to (1) are under active discussion with the states and other Federal Government agencies. NBS is now developing a radiation calibration facility for neutron personnel monitoring with ERDA support.

Four medical radiation user groups have been identified: radiation therapy, diagnostic x-rays, dental x-rays, and nuclear medicine. About 350,000 patients are treated with radiation therapy per year, representing 50-60% of cancer cases. In 1970, 129 million persons received 210 million diagnostic x-ray examinations. In 1971 there were more than 105,000 diagnostic x-ray machines and 117,000 dental x-ray machines. In 1971 there were eight million applications of radiopharmaceuticals given for diagnosis. One patient in four entering the hospital will be administered radioisotopes for diagnostic test(s). Measurement needs apparent include: (1) wider dissemination of NBS dosimetry calibrations; (2) development of primary absorbed dose standards for high-energy (linac and betatron) x-rays and for fast neutron radiotherapy; (3) extension of a system of quality control throughout the approximately 8,000 institutions doing nuclear medicine; (4) straightening our of problems with radionuclide dose calibrators. In each case NBS actions are underway or being developed with others to meet these needs.

The study of nuclear power is concerned with: nuclear fuel cycle operations, and design data and reactor operations. A special study by John W. Bartlett, Assessment of the Nuclear Fuel Materials Measurement System, found that the need for accurate accountability of fissionable materials stems not from buyer-seller equity but rather from the need to safeguard nuclear material. It seems certain that there will be a need for NBS participation in and technical assistance for a major measurement assurance system for nuclear fuel materials accountability, and discussions on this subject are underway between NBS and the Nuclear Regulatory Commission. At present, NBS programs are responding to needs for new Standard Reference Materials, improvement of the technical base for calorimetry, collaboration with the ERDA New Brunswick Laboratory in support of the measurement assurance activities of the Safeguards Analytical Laboratory Evaluation (SALE) program, and analysis of materials diversion paths and data requirements.

In the area of design data and reactor operations, needs are for standards for neutron cross section measurement in support of

LMFBR (liquid metal fast breeder reactor), HTGR (high temperature gas-cooled reactor), and thermal neutron power reactor programs; and for measurement standards for in-reactor measurements of neutron flux and spectra and fission rates in fuel elements. For fission reactors improved cross sections are needed for shielding, fuels, neutronics of structural materials, integrity of reactor components, and reactor control and safety. For fusion reactors, nuclear cross section data needs are less immediate; but data will be needed for shielding, heat transfer element design, tritium breeding design, integrity of structural materials, and induced radioactivity problems. Standards for in-reactor measurements of neutron flux and spectra and fuel element fission rates are important in testing reactor performance versus calculations, testing of fuel, temperatures of fuel, reactor lifetimes, power level, control, and safety. A neutron standards program in NBS aimed at greatly improving the accuracy of standard reference neutron cross sections, and neutron fluxes used to measure other cross sections, and providing standard reference neutron fields for the basis of in-reactor neutron measurements is now at full strength using the NBS linac, Van de Graaff, and reactor.

The field of industrial radiation processing continues to grow, although more slowly than indicated by some earlier predictions. The energy crisis may, in fact, speed development in this area since radiation processing uses less energy than do corresponding thermal processes. NBS offers calibration services for the megarad disometry range on a limited basis. Establishing measurement service requirements is somewhat hindered by the proprietary nature of this field and the high degree of industrial secrecy. Some new needed calibration services are being developed, but no needs for major new programs have been identified.

The study of radiation measurement for national defense has identified needs in the area of high-intensity, pulse x and gamma radiation measurement. The NBS action in response has been development of new orders-of-magnitude more intense calibration sources. Defense Department needs in the measurement of radioactivity appear to have been met by NBS programs for development of radioactivity standards, particularly for the noble gases.

The study of environmental radiation measurement identified a need for environmental radioactivity standards and for environmental radioactivity measurement assurance testing. NBS has recently developed a new series of mixed radionuclide environmental radioactivity standards which are now available to the environmental measurement community, and many measurement assurance tests are being carried out to help members of the community and lead laboratories of ERDA and EPA test and improve their measurement performance. State laboratories receive NBS-traceable standards from and participate in measurement assurance testing with the ERDA and EPA measurement laboratories.

In the areas of science and chemical analysis, existing programs in support of these fields need to be continued. For science, a data compilation effort on charged-particle stopping powers, ranges, straggling and delta-ray production below about 10 MeV is needed.

Miscellaneous radiation applications include radiographic equipment, gauges, irradiators, oil-well logging apparatus, self-luminous products, smoke detectors, static eliminators, and heat sources. The annual business in these devices is in excess of 70 million dollars. The most stringent requirements for accurate measurement appear to be at the manufacturing level. A chief problem is the need for adequate safety measures in the use of this equipment. This problem is being attacked through vigorous NBS participation in voluntary standards committees such as American National Standards Institute (ANSI) Committee N43 which is concerned with promulgating recommendations for safe use of radiation equipment.

A number of common threads stand out quite strikingly in the studies of the various users of radiation: (1) There is often a need for new NBS measurement standards where they do not exist--however, where NBS measurement standards do exist their accuracy is generally sufficient for present needs. (2) There is a great need for measurement assurance, especially where regulatory requirements are involved. Usually priorities found in this study are much higher for dissemination of standards to users and carrying out measurement assurance testing than for development of new measurement standards. (3) A need exists for help to the poorly-qualified user--training, convenient laboratory standards, handbooks for guidance. (4) A single measurement system under NBS leadership is needed to help both regulators and users, to avoid duplication and competition among regulators, to simplify the radiation users' problems of measurement and reporting, and to protect the health and safety of the public. (5) Needs for NBS to play its traditional "independent third party" role are often found.

USCOMM - ERL

NBS-114A (REV. 7-73)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR 75-947	2. Gov't Accession No.	3. Recipient's Accession No.
4. TITLE AND SUBTITLE Collected Executive Summaries Studies of the National Measurement System 1972-75			5. Publication Date August 1976
			6. Performing Organization Code 270.00
7. AUTHOR(S) Raymond C. Sangster, Editor			8. Performing Organ. Report No.
9. PERFORMING ORGANIZATION NAME AND ADDRESS NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234			10. Project/Task/Work Unit No. 2700916
			11. Contract/Grant No.
12. Sponsoring Organization Name and Complete Address *(Street, City, State, ZIP)* National Bureau of Standards, Institute for Basic Standards Office of the Deputy Director, IBS/Boulder 325 Broadway Boulder, Colorado 80302			13. Type of Report & Period Covered
			14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report contains the Executive Summaries of the reports of the 1972-75 study by the NBS Institute for Basic Standards of the U.S. National Measurement System, which consists of all of the activities and mechanisms which provide physical measurement data required by our society. A series of microstudies focused on specific technical measurement sectors. A macroeconomic study looked at costs of instrumentation and labor for measurement-related activity in our economy. University economists were retained to assist the microstudy authors and to prepare an overall economics report. A central coordinator set a basic pattern for the microstudies, prepared an overall summary report, and generated several documents relating to the system as a whole. Abbreviated titles of the executive summaries are: Final summary report. Direct measurements transactions matrices. Economic analysis. Structure and functions of measurement system. Time and frequency. Length and related dimensional measurements; vibration and shock. Surface finish. Mass, volume and density. Force. Fluid flow. Pressure. Temperature. Humidity and moisture. Thermodynamic properties of fluids. Cryogenics. Electricity. Electromagnetics. Medical ultrasonics. Acoustics. Radiometry and photometry. Spectrophotometry. Far ultraviolet radiometry. Optics. Physical properties of atoms and molecules. Surface properties. Ionizing radiation.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Acoustics; atomic properties; economics; electrical quantities; ionizing radiation; mechanical quantities; national measurement system; optical quantities; surface properties; thermal quantities; time and frequency.

18. AVAILABILITY	19. SECURITY CLASS (THIS REPORT) UNCLASSIFIED	21. NO. OF PAGES 53
[XX] Unlimited [ ] For Official Distribution. Do Not Release to NTIS [ ] Order From Sup. of Doc., U.S. Government Printing Office Washington, D.C. 20402, SD Cat. No. C13 [X] Order From National Technical Information Service (NTIS) Springfield, Virginia 22151	20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	22. Price $4.50

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